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Balancing Unintended Disruptions in Motion

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Balancing Unintended Disruptions and Motion

By

Eric J. Johnson

An Interactive Qualifying Project

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of the

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in partial fulfillment of the requirements for the

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Mechanical, Robotics and Manufacturing Engineering

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ABSTRACT

The goal of this project is to gain a better understanding of how force plates can help patients in medical need and distinguishing injured from healthy patients electronically through the analysis of forces and moments of motion as functions of time. Looking at the disruptions in the human motion, a force plate can record force and moment data to help determine the status of a patient in need. This project studies the amplitude, energy, and frequency of road vibration when a force plate is inserted into an ambulance, and analyzes the effect of the vibration on the quality, and efficiency of care during ambulance ride. Factors such as road conditions, speed, and suspension systems all play vital roles in understanding how vibration influence patient care. Working with Boston and Worcester Emergency Medical Technicians, and studying past research work on the influence of vibration on patient care and ambulance ride, an overview of the implications and recommendations for safe ambulance ride is developed.

CHAPTER 1: THE IMPORTANCE OF BALANCING UNINTENDED MOTION DISRUPTIONS

1. Introduction

Over the next decade the population is expected to expand dramatically in an ever-changing world. As a result of this continuous increase in world population, emergency response systems have become more important than ever before. In the United States and the rest of the World, the call volumes for medical needs are growing and will only continue to do so as time passes. Not only will the quantity of calls increase, but also the quality of the responses will have to acclimate as newer technologies are implemented. This project aims at improving the ambulance ride by measuring force feedback of a load resting on AccuSway Force Plates in an ambulance compartment. This will aid to better understand the influence of road vibration on occupants in the ambulance compartment. A force plate is a device used to measure the forces and moments applied to its top outer surface. It can record force as a load is placed on it. Force plates are regularly used in research and clinical studies looking at balance, gait, and sports performance in various patients or subjects. Forces are measured in three directions, namely F_x , F_y , and F_z which act along the axes of an orthogonal x , y , z -coordinate system. M_x , M_y and M_z are the three moment components corresponding to the x , y and z -axes. Positive moments are determined according to the right hand rule. When looking down an axis (in its positive direction),

positive moments have a clockwise rotation. In **Figure 1**, one can see the direction of the positive forces along each of the axes, F_x , F_y and F_z .

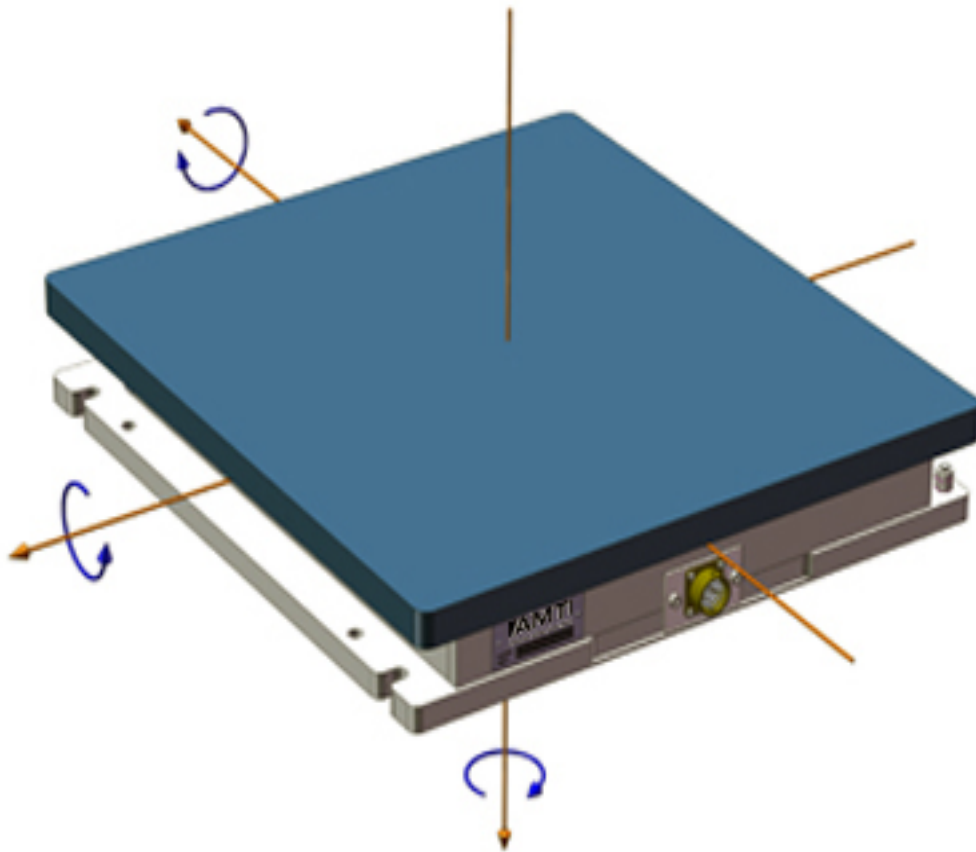


Figure 1 – Force-Plate and Momentum Diagram

A force-plate in an ambulance can provide an opportunity to monitor and control vibration induced by different road surfaces. The goal of this project is to understand the mechanics of force plates, and how they can be used to monitor and control the occurring force and displacement feedbacks during ambulance ride. Chapter 2 contains the types of force plates and their general applications. In Chapter 3, the mechanics of the force plate

is presented and its role in evaluating the forces induced by road vibration into the ambulance compartment. The discussion of the derived results and their impact are in Chapter 4.

CHAPTER 2: PRACTICAL USES IN TODAY'S WORLD

2. Introduction

In the current age there are many practical uses for force-plates in today's world. Some of the most common uses include the following: human and animal gait studies, balance assessment and training, underwater force measurement, prosthetics and orthotics evaluation, sports performance analysis, ergonomic studies, and finally but not limited to rehabilitation and physical therapy. Human and animal gait study is the research done on a subject's ability to stabilize itself under various amount of loadings or activities. Underwater force measurement aids in determining the magnitude of force underwater treadmills may have on a rehabilitating occupant. Prosthetics and orthotic testing can be done with the use of force plates. If one stands on the force plate with and without orthotics, the individual can accurately verify if there has been an improvement in motion stability. Force plates can be found in the sports world as trainers use them to gauge the strength of patients in rehabilitation over a period of time. The section next shows how force-plates are applied to everyday life, and how one could incorporate them into an ambulance compartment.

2.1 Practical Uses

2.1.1 Prosthetics and Orthotics Evaluation

Prosthetics and orthotics have always been a popular area of modern medicine wherein use of the technology of force-plates is very important. Dr. Scholl as it is widely known, offers a machine that one can stand on and instantly shows force readings and locations where the forces are the largest. Many people have high or fallen (collapsed) arches in their feet and need something to accommodate the strain being placed on the

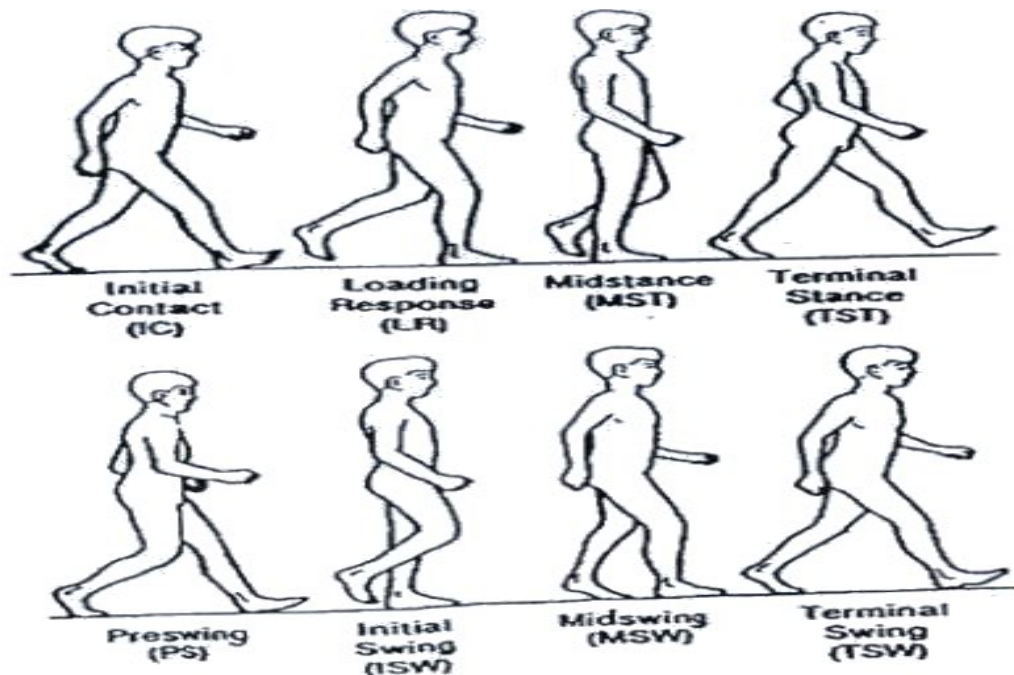
body. **Figure 2** shows a woman using Dr. Scholl's machine that is infused with force-plates. The AccuSway force plate in the machine provides information about foot or whole motion characteristics and selected physiological signs. Without the information that the force plate can provide for you with this machine, one would ultimately have to result to scheduling an appointment with a podiatrist to get a proper evaluation.



Figure 2 – Dr. Scholl's Machine Using a Force-Plate

2.1.2 Human and Animal Gait Studies

Animal and gait studies are involved with the study of locomotion. Locomotion is the act of self-propulsion by means of doing an activity such as walking, running, swimming, jumping, or flying. Gait studies are generally used to treat individuals or animals that have conditions that affect their ability to walk or maneuver around. A human or an animal can be placed on a force plate to evaluate the strength and weakness its maneuvering capabilities. Human gait studies applied to athletes can help one determine the overall correct posture for the running motion, as seen in **Figure 3**. The use of biomechanics aids in this process by isolating posture related problems as they happen in real time. Force plates measure the moments, and the ground reaction force as the patient performs motions.



The Descriptive Stages of the Gait Cycle

Figure 3 – The Descriptive Stages of the Gait Cycle

2.1.3 Balance Assessment and Training

Force-plates can be used to help aid one in balance training due to the fact that when one is standing on them the weak areas in the subject's feet shows up as pressure points on a graph. After looking at the data and assessing where the weak points are, one can locate the position wherein balancing is attainable. **Figure 4** shows a force-plate conducting a balance analysis test.



Figure 2. Subject's position on the force platform (model BIOMECH400) during one-leg standing for balance test.

Figure 4 – Woman Performing a Balance Test

2.1.4 Underwater Force Measurement

Force-plates can also be used in rehabilitation swimming pools to aid physical therapy. Underwater treadmills aid in underwater physical therapy by allowing an individual to work out with the resistance of water. Underwater biomechanics are made possible with AMTI force plates implemented into specific underwater treadmills. Data can be collected from this in real time, and compared to out of water ones performance to determine where the affected areas are. Underwater treadmills either entail a treadmill inside a tank or a passive treadmill that is placed inside a pool of water. The basic idea is that the treadmills can offer a standard aerobic workout along with elements of muscle strengthening, weightless comfort, and resistance that the normal treadmill cannot offer.

Figure 5 shows what an actual underwater treadmill looks like in action.

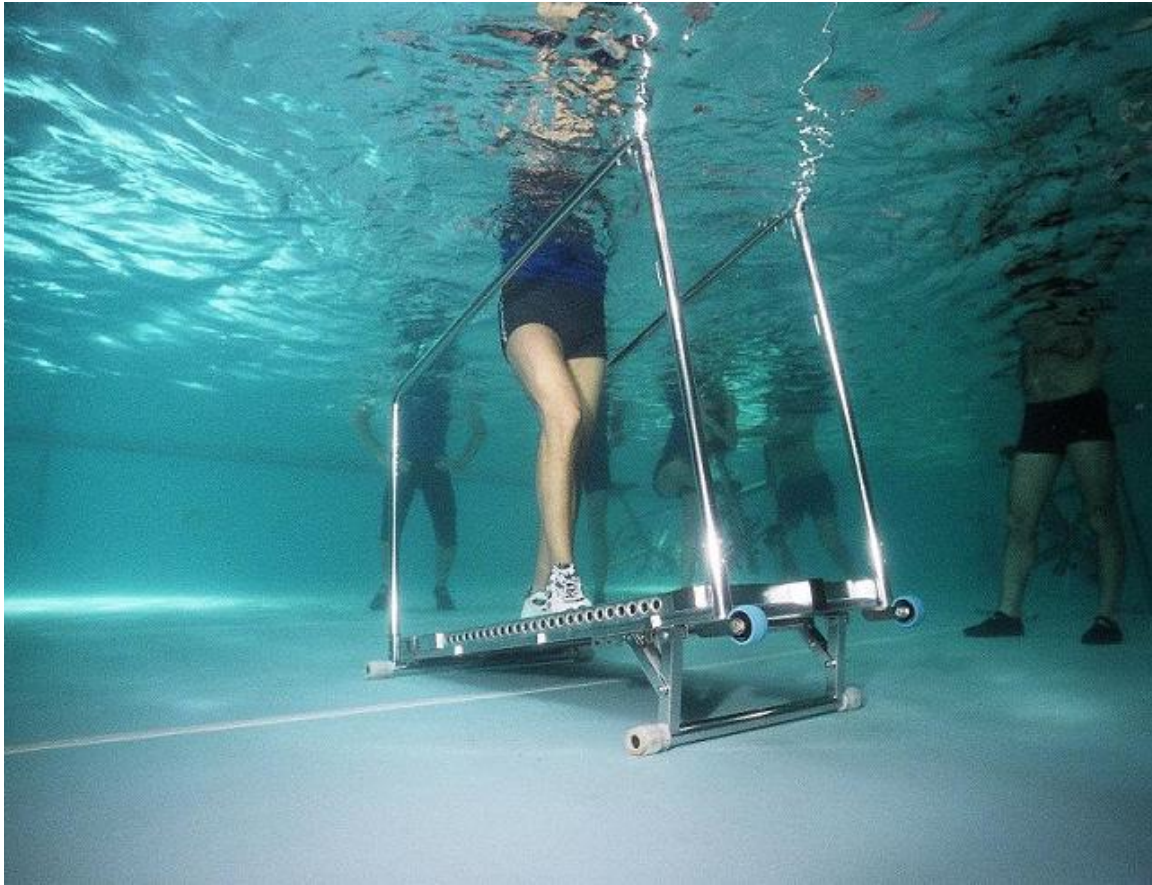


Figure 5 – Underwater Treadmill

2.1.5 Sports Performance Analysis

Athletes are always trying to gain a competitive edge over surrounding players they are involved with. If a football running back is to take a sport performance analysis test one can verify the performance such as how fast one can make a cut while running. The amount of force applied to an effected area when one makes a pivot, turns around, and goes in the reverse direction, can be measured with the technology of the force-plates. The popular show SportsCenter has a segment called “Sports Science” that analyzes the actual values of the physiological signs and motions of the athletes and the human body.

Their labs most definitely use the technology of force-plates to determine this type of information. **Figure 6** shows an athlete coming to a stop and pivoting in the opposite direction. The force plate can be applied to the athlete's feet to determine the characteristics of the motion and physiological signs.



Figure 6 – Athlete Making a Stop In a Performance Test

2.1.6 Ergonomics Studies

Ergonomics is the study of designing equipment and devices that specifically fit the human body. A question can be asked how a force-plate would be helpful in aiding the collection of data to build these products. **Figure 7** shows example of what ergonomics actually are. Through the use of force-plates mass data can be harvested and compiled into large scales. For example if one million people were stand on a force-plate and everyone's footprints (pressure points) were compiled into data, one could find the most generic design for a specific population. This could be particularly useful in the manufacturing and design of shoes, and how they should fit an average foot size.

Viewing Distance & Monitor Height

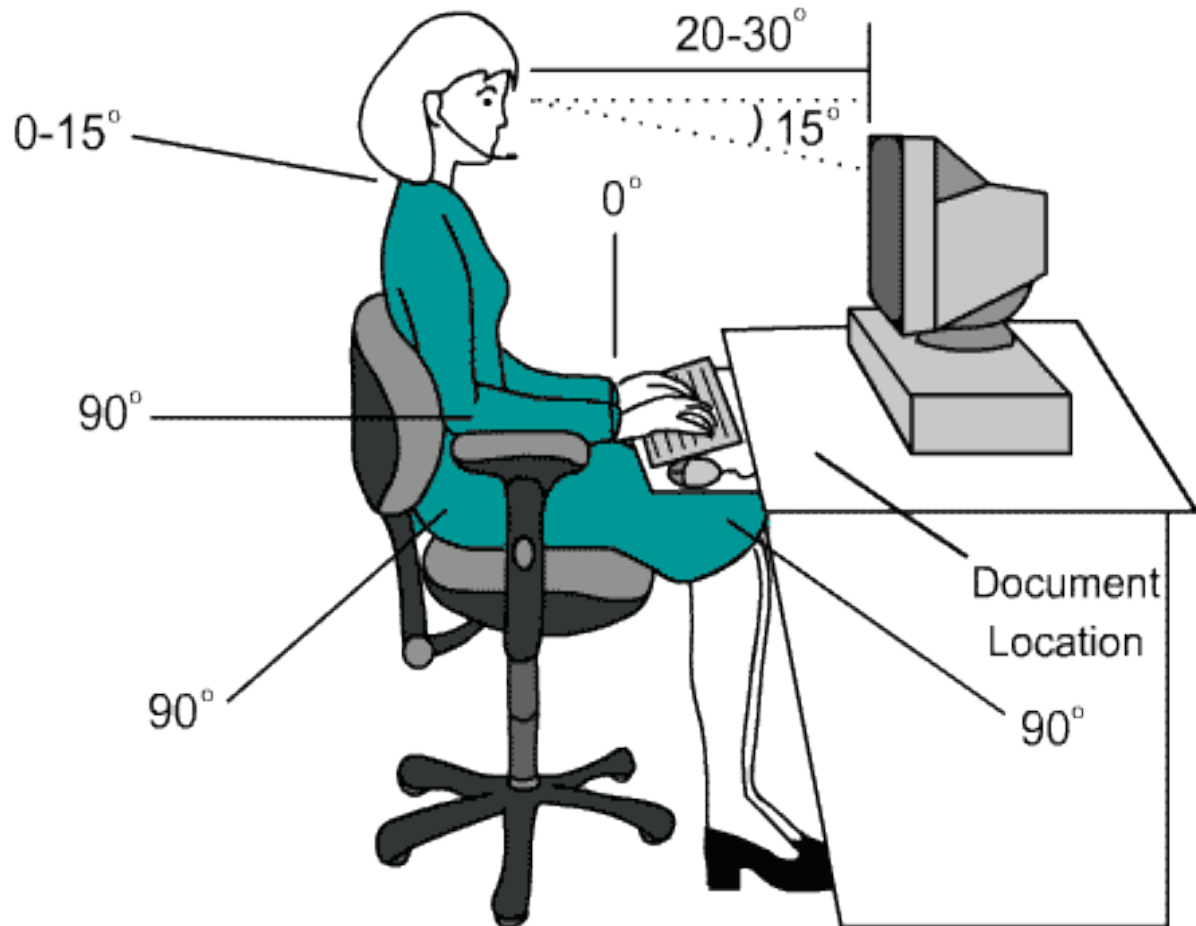


Figure 7 – Ergonomic Product Model

2.1.7 Rehabilitation and Physical Therapy

Physical therapy is a huge field applied to everyday life to aid in the rehabilitation process for an individual who is in need of a treatment. Through the use of force-plates one can do physical therapy and view the results in real time, as opposed to just assuming the treatment or activity. **Figure 8** shows the different products made by AMTI that aid in the process of rehabilitation and physical therapy.



Figure 8 – Therapeutic Products by AMTI for Rehabilitation

2.2 Practical Uses in a 553C Ford Ambulance

The main practical uses for a force plate in an ambulance would mainly be that one wouldn't have to travel to a permanent location in order to obtain a diagnosis. The ambulance can easily provide enough electricity to power the force-plate and can easily be connected to an onboard laptop to collect data. Depending on the height of the patient and the height of the ambulance, one could actually stand on the force-plate and perform

physical analysis. Ambulances are typically heavy and sudden reduction of vehicle speed is a challenge for many drivers. Force-plates can support the gradual reduction vehicle speed in a sustained way. If force-plate type sensors were installed in the chassis the efficiency of maneuvering around corners could be increased with accurate force readings. **Figure 9** shows an example of an ambulance that is of good size.



Figure 9 – Large Scale Ambulance

2.2.1 Pregnancy Aid Using Force-Plates

One of the most common calls an ambulance receives is when someone is sick or being injured and needs to prehospital care. Most of us can probably imagine, that ride to the hospital is extremely crucial that things go smoothly and that is extremely important. Generally the woman in labor would be sitting in a stretcher attached to the floor of the

ambulance. If the stretcher was altered to include a motorized stabilizer and a force-plate to tell the stabilizer what to do, this ride can ultimately become significantly more comfortable for the patient. Pregnancy is painful enough for the client, and it would only make sense that accommodations be provided for the patient in need. These types of things generally get overlooked due to the cost and how complicated it actually would be to build an instrument that could perform these actions. **Figure 10** shows today's typical delivery bed that an ambulance could provide for a woman in labor.



Figure 10 – Ambulance Delivery Bed

2.2.2 Human and Animal Gait Studies

Human and animal gait studies wouldn't necessarily be practical to use in ambulances, however the idea is not impossible. If an athlete was having a problem and an ambulance was on site, one could do a gait analysis. If the cords were elongated and laid outside the ambulance one may be able to perform the test seen in **Figure 11**.

Gait Cycle

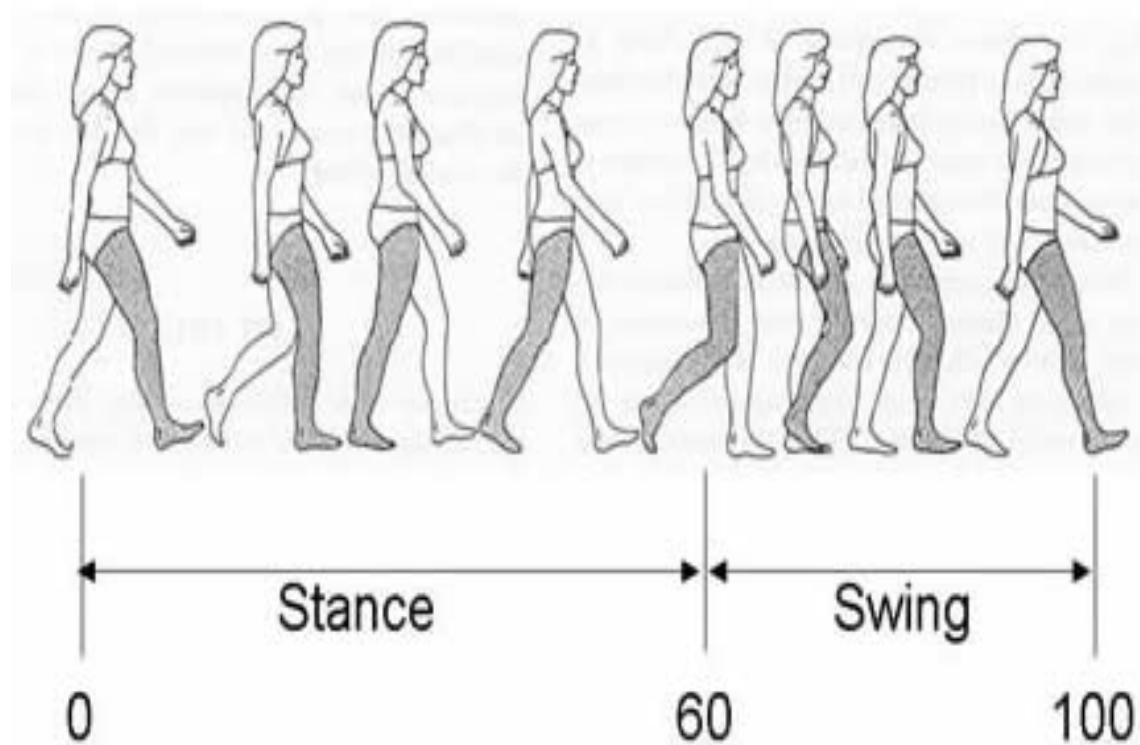


Figure 11 – Typical Gait Cycle Test

2.2.3 Balance Assessment

Balance assessment is much more practical to use on-board an ambulance in the event someone was in need of it. The use of force-plates can ultimately help determine the ability of one to balance if need be. A typical reason for a balance test would be to test for a concussion. Concussion tests require you to do a series of balancing exercises that determine whether or not you are fit to participate in a particular sport. **Figure 12** shows a typical balance test that is found while performing a concussion test. The machine used in that picture uses the technology of force-plates to generate data regarding the ability an individual has to balance. Given the size of the ambulance, this

machine could be installed inside to aid users in need.



Figure 12 – Balance Performance Machine

2.2.4 Stability Control Maneuvering Ambulance

The installation of sensors in ambulances can aid the driver to maneuver with an abundance of ease. An example of this technology implicated into cars would be the Mercedes Benz cars that stop automatically when they detect the operator has applied an excessive amount of force to a particular wheel or side of the car. If the data collected

from the force sensors was relayed to the drive of the ambulance, the driver could monitor how much force he is putting on each tire when taking crucial turns. **Figure 13** shows exactly where one would implicate force sensors into a vehicle for beneficial purposes.

MEMS inertial sensor cluster concept

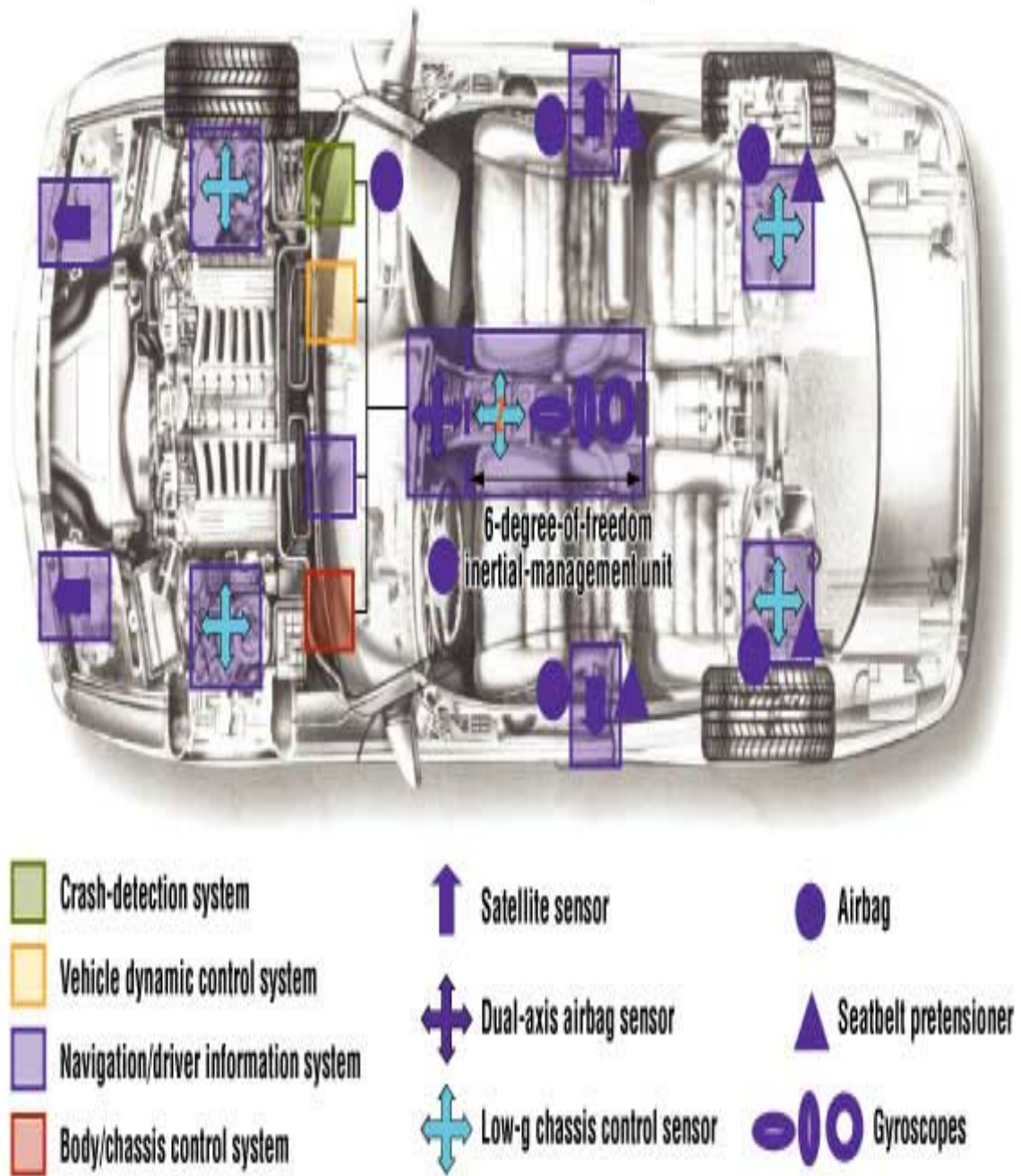


Figure 1. The concept of MEMS inertial sensor clusters is being proposed for managing a vast array of automotive sensing applications. (Source: "MEMS make cars smarter," Harvey Weinberg, Analog Devices)

Figure 13 – Car with Force Sensors

CHAPTER 3: CASE STUDIES INVOLVING FORCE-PLATES

3. Introduction

Force-plates come in a variety of shapes and sizes that measure all types of things, all while aiding the user in a positive way. There are a number of case studies that show the positive possibilities that force-plates ultimately bring to the table.



Figure 14: AMTI Forceplate

AMTI'S force-plate has six-axis biomechanical products that represent more than 30 years of research. Their excellent performance and long-term durability have made them the worldwide standard in gait and biomechanics laboratories. (Biomechanics Overview)

The following case studies show the positive influence that force-plates have on the world.

3.1 Road Conditions While Driving at a Constant Velocity

Doctor Paul Cotnoir, conducted a study in 2010 focused on classifying the various modes of vibration experienced by riders specifically in an ambulance. The purpose of his study was to develop a computational model which ultimately describes these vibrations in order to facilitate further research into the pathophysiological affects of certain vibrations on ambulance patients and EMTs. To determine the vibrations, Dr. Cotnoir conducted a series of tests using various ambulance models. These tests accounted for different roadway conditions and various vehicle velocities.

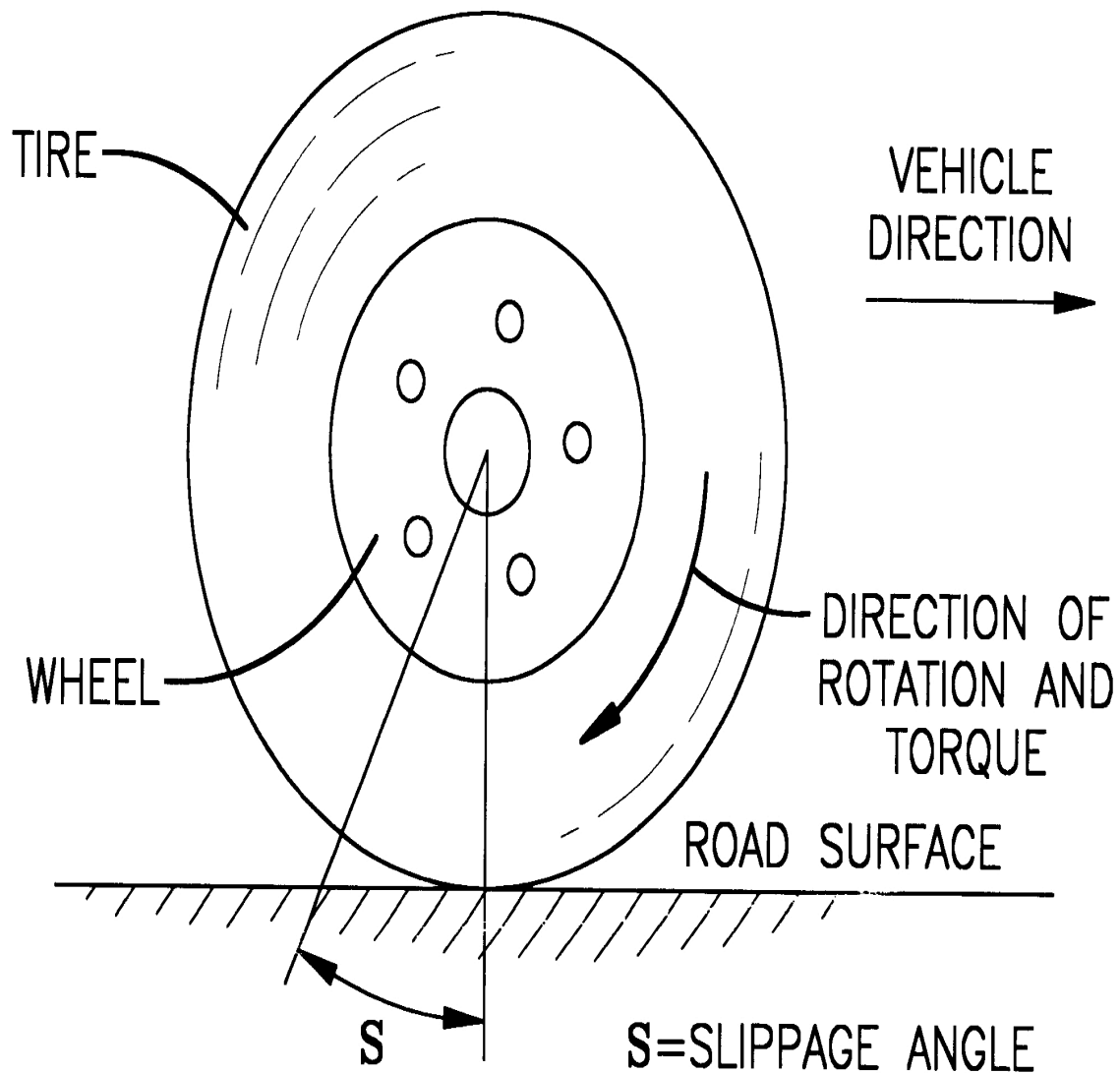


Figure 15: Constant Velocity Slippage

The end result of the experiment was an analytical model that can be used to create control law equations for use in active vibration dampening systems.

Four different ambulances were ultimately used, each of which met current standards outlined by the KKK-A-1822 star-of-life standards. The first vehicle was a Type I model built by Horton. The “Type” of an ambulance describes the type of chassis the vehicle is based off of; I being a truck and III being a van. Its chassis was a 2005 Ford F450 with a standard leaf spring and shock absorber suspension weighing 16000 lbs. This

vehicle was ultimately borrowed from UMASS. A second ambulance was also borrowed from UMASS, and this ambulance was a 2008 Chevrolet C4500 from the body manufacturer known by the name of Braun. This second vehicle was also a Type I model with a standard leaf spring and shock absorber suspension, although it only weighed 16500 lbs. The third vehicle was a 2001 Ford E450 borrowed from Putnam, CT EMS, also with the standard leaf spring and shock absorber suspension weighing 14050 lbs. Unlike the two previously mentioned ambulances, this was a Type III. The final ambulance used for the testing was a Type III, 2009 Ford F550 with an air ride suspension. This ambulance, weighing 17950 lbs., was borrowed from Woodstock, CT EMS. Using these four vehicles Dr. Cotnoir measured vibrations on varying road surface conditions and at varying speeds. Each vehicle was driven on four different road conditions characterized visually. From most vibration excitation to least, these conditions were unpaved road, paved secondary road, paved city street, and finally paved multi-lane highway. Although generally in that order, all roads contained random points of irregularity including potholes, frost heaves, speed bumps, and severely worn sections of road. The intent of the testing was to characterize each surface condition using the full range of velocities, but due to speed limits, only certain speeds could be tested on each road type.

The unpaved road consists of dirt, stone, gravel or sand with variable methods of construction. The road width varied with location but usually stays under 9.1 meters (30 feet) wide. The maximum allowable speed differed or was not shown at the various locations. The paved secondary road, or rural paved road, is broken into a new and old subclass based on different construction methods and compositions of when it was paved. The new rural paved road consists of 76 to 102 millimeters (3 to 4 inches) of bituminous

concrete or hot-mix asphalt (HMA), which is poured over a base of gravel approximately 305 millimeters (12 inches) deep. The old rural paved road is constructed using up to 127 millimeters (5 inches) of asphalt paving on an existing base. The width of the rural roads is typically less than 9.1 meters (30 feet). And the maximum allowable speed ranged from 56 to 72 kilometers per hour (35 to 45 miles per hour).

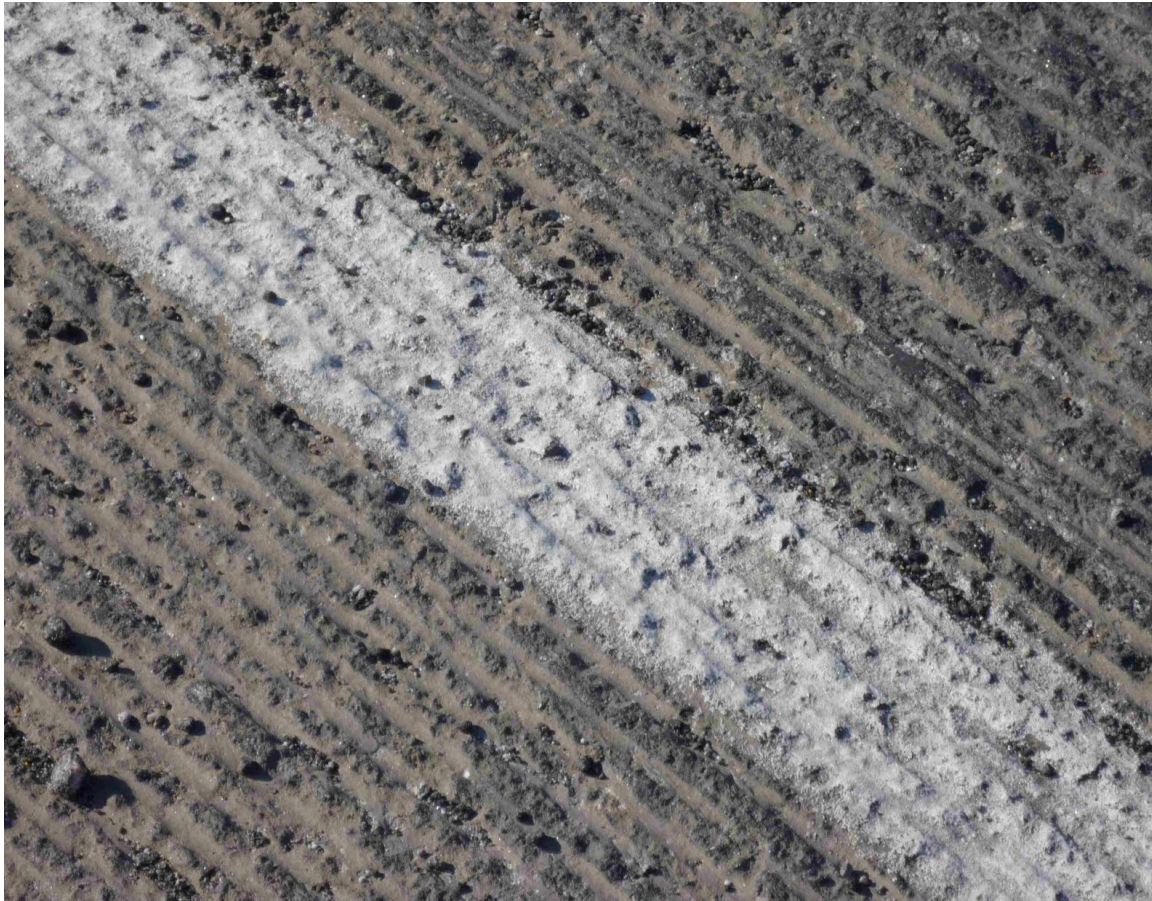


Figure 16: Grooved pavement commonly found on streets during construction

The paved city street and parking lot also is broken into a new and old subclass. The new city street, like the paved secondary road, is composed of 76 to 102 millimeters (3 to 4 inches) of bituminous concrete or hot-mix asphalt (HMA) poured over a gravel base approximately 305 millimeters (12 inches). And the old city street uses 127 millimeters (5 inches) of asphalt paving on an existing concrete or cobblestone base.

Even though the paved city street is composed of the same material as the rural paved roads, the city street has a 2-3% cross slope for drainage of rain water, and the speed limit varied from 24 to 56 kilometers per hour (15 to 35 miles per hour). Other differences between the city street and the rural road are the volume of traffic flow, how often it is maintained, and other minor variables.



Figure 17: Complex highway systems

The paved highway has three different construction methods. The flexible pavement uses three to four courses of hot mix asphalt (HMA) over a granular sub-base. The rigid pavement is either a plain and jointed or continuously reinforced layer of

Portland cement concrete over a granular sub-base. And the composite pavement consists of one or more courses of hot mix asphalt (HMA) over a Portland cement concrete base. These three subclasses of the paved highway are used for the various locations of where it needs to be laid, such as on an overpass or on the earth.

All roads that vibration data were collected from were categorized into those four road types. A simple visual classification method was used to establish whether it was unpaved, secondary, city, or highway. All tests were conducted using four different ambulances which were set up as similar to one another as possible. Each ambulance and the data collection apparatuses were set up in the same manner every time it went out on the test runs to remove variables. Overall the major contributing factors that affected the vibration sensors were the road type, the ambulance that was used, and the speed at which the ambulance was driving.

Table 1: Test Summary. Consists of the number of events recorded.

Amb #	Total # events	Event ¹ #'s							
		Highway			Secondary road		City street		Un-paved road
		≤35 mph	36-64 mph	≥65 mph	≤35 Mph	36-64 mph	≤35 mph	36-64 mph	≤35 mph
1	64	1-3	4-6; 15-20	7-14	21-23; 27-29	24-26; 30-32	41-64	38-40	33-37
2	63	1-3	4-6; 10-15	7-9; 16-18	25-27; 50-52	31-33; 58-60;	19-24; 44-49; 61-63	28-30	34-43
3	71	1-3	4-6	7-15	16-18; 22-24	19-21	34-58	31-33	25-30
4	93	16-18	19-24; 31-35	25-30	4-6; 10-12	1-3; 13-15; 41; 43-45	7-9; 34-36; 49-58; 68-70; 77-82; 91-93	37-39; 59-67	71-76

In **Table 1**, the number of events in which data was acquired from the experiment

has been compiled and sorted by road type, ambulance, and speed. Each event is a ten second time frame in which vibrations were recorded while driving in the appropriate categories. For safety reasons and obeying the speed limit, not all road types were tested at the higher speeds. The data recovered from these events follows ISO and British vibration measurement standards. The focus of this study is vertical vibration. Z-axis vibration is the most present vibrations that affect the patient lying supine in the stretcher.

Table 2: Vibration amplitude data on various road surfaces

Overall amplitude of vibrations (z-axis)					Amplitude of bumps and shocks (z-axis)					Uniformity of vibration amplitudes (z-axis)				
Mean r.m.s. (m/sec ²)					Mean peak (m/sec ²)					Mean crest factor				
For all speeds, all ambulances, highway travel														
\bar{x}	Min	Max	<i>s</i>	n	\bar{x}	Min	Max	s	n	\bar{x}	Min	Max	s	n
0.89	0.59	1.63	0.31	73	4.28	3.07	7.25	1.20	73	5.20	4.04	6.98	0.99	73
For all speeds, all ambulances, secondary road travel														
\bar{x}	Min	Max	s	n	\bar{x}	Min	Max	s	n	\bar{x}	Min	Max	s	n
0.93	0.50	1.34	0.28	49	4.65	2.50	6.42	1.40	49	5.18	4.20	6.06	0.56	49
For all speeds, all ambulances, city street travel														
\bar{x}	Min	Max	s	n	\bar{x}	Min	Max	s	n	\bar{x}	Min	Max	s	n
0.90	0.60	1.29	0.26	110	4.90	2.92	8.03	1.71	110	5.71	4.47	7.70	1.00	110
For all speeds, all ambulances, unpaved road travel														
\bar{x}	Min	Max	s	n	\bar{x}	Min	Max	s	n	\bar{x}	Min	Max	<i>s</i>	n
1.54	0.46	2.55	1.09	27	8.44	1.87	15.45	7.06	27	4.97	3.95	5.99	0.96	27

In **Table 2**, all the raw data is analyzed and sorted by road type. The vibrations gathered from the experiments were then calculated into the mean r.m.s, mean peak, and mean crest factor as can be seen in that chart as well. The mean r.m.s is an analysis upon the acceleration where the average of the root mean squares is taken for all the ten second interval recordings. The root mean squares are calculated by squaring each crest peak number in each ten second time frame, then taking the square root of the average of those numbers. The mean r.m.s. shows the average acceleration due to the vibrations. The mean peak acceleration takes the largest absolute amplitude value from each ten second time frame and then finds the average of all the combined maximum peak values. The mean peak acceleration displays the average of the largest impacts in each ten second recording time frame. The mean crest factor is calculated by dividing the mean peak acceleration for each ten second event by the r.m.s acceleration of that sample. All these are broken up into standard deviation format.

3.2 Balance and Mobility Following Stroke

Visual biofeedback force-plate systems are often used for treatment of balance disorders. In this study, the researchers investigated whether the addition of visual biofeedback/force-plate training could enhance the effects of other physical therapy interventions on balance and mobility following stroke. (Balance and Mobility Following Stroke: Effects of Physical Therapy Interventions With and Without Biofeedback/Force Plate Training). They tested a number of different subjects who ranged from ages 30 to 77 years of age, who were anywhere from 15 to 538 days past having a stroke. The study tested their cognitive and visual skills to test the acuteness of the patients. After the cognitive analysis was performed, a balance test was used using a Berg Balance Scale,

and a NeuroCom Balance Master. After these tests were performed it was seen that both groups of people scored significantly higher on the balance tests, which help to correspond with increased independence of balance and mobility in the study population. (Balance and Mobility Following Stroke: Effects of Physical Therapy Interventions With and Without Biofeedback/Force Plate Training).



Figure 18: Stroke patient in recovery

3.3 Force Platform Recordings in the Diagnosis of Primary Orthostatic Tremor

Primary orthostatic tremor (OT) consists of rhythmical muscle contractions at a frequency of around 16 Hz, causing discomfort and/or unsteadiness while standing. Diagnosis has hitherto relied on recording Electromyography (EMG) from affected muscles. The main aim of this study was to see if the characteristic postural tremor in OT can be identified with force platforms. ("Hexicon Fantasy Roleplay - Fantasy Made Real.") When an individual stands on a force-plate, even if you are standing perfectly still, you tend to sway and emit the tiniest movements. Before intricate machines such as force plates one had to diagnose patients with the naked eye and make speculations based on what they saw. This method may have been beneficial at a certain point in history, however there is no mathematical calculations happening (or data being collected) when one is simply observing an individual in need of treatment. Though the technology of force-plates one can pick up the actual moments of sway that happens. Looking at that data one can analyze the correct (or incorrect) posture of an individual. It was concluded that OT patients showed increased sway at low frequencies, which helps us to understand that the unsteadiness is partly due to increased postural sway. These data show a high correlation between EMG and posturography and confirm that OT may be diagnosed using short epochs of force platform recordings. ("Hexicon Fantasy Roleplay - Fantasy Made Real.")

3.4 A Kinematic and Kinetic Case Study of a Netball Shoulder Pass

The majority of studies analyzing netball skills using force platforms have focused

on reducing the risk of injury from compression and torsion forces on the knee and ankle joints during landing and pivoting. In this preliminary case study our aim was to investigate the efficacy of a combination of tools to describe the kinematic and kinetic mechanisms underlying the netball shoulder pass. (TopSCHOLARÂ®). The movements of the netball shoulder pass were analyzed using video feedback and the force platform. Data was collected in order to develop sizable data for use in a much larger study. Peak vertical ground reaction force of 850 N was found to coincide with the point of maximum velocity of the centre of pressure, occurring 40 ms before ball release. The participant's centre of pressure continued interiorly for 40 ms after ball release.

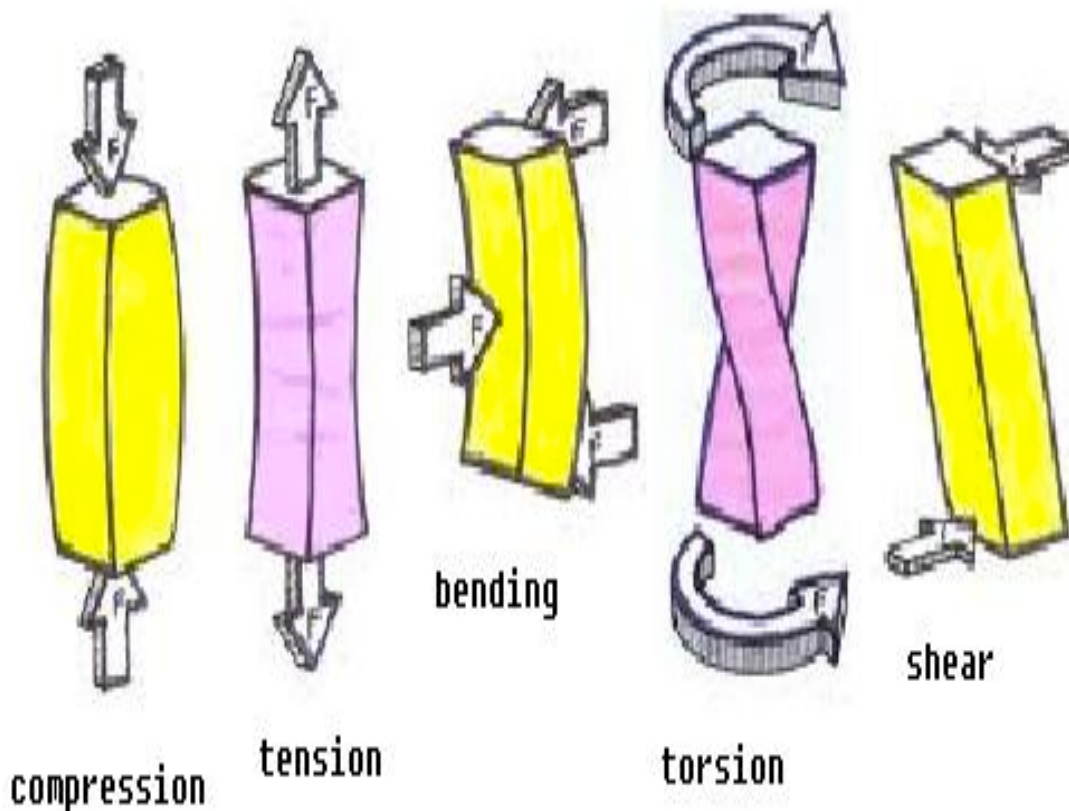


Figure 19: Commons forms of tension and torsion

The wrist traveled in a linear path during the propulsion phases, maximizing impulse to the ball. A large shear force also occurred in the anterior posterior direction coinciding with ball release due to friction between the left shoe and the force platform, resisting the forward momentum of the body. Negative acceleration of the upper limb following the propulsion phase reached a peak of 68.6 rad/s^2 for the arm and 82.4 rad/s^2 for the forearm. Peak shoulder deceleration torque was calculated at 4.1 Nm , which was greater than during acceleration (1.6 Nm) (TopSCHOLAR®). The combination of kinematic and kinetic tools yielded a comprehensive analysis of the investigated skill that can help determine the difference between average and professional athletes. The technology continues to show the importance of force-plates and how beneficial they actually could be given the right circumstances.

3.5 The Use of Force-Plates for Jumping Research

The force plate is becoming a basic tool used in the study of jumping activities, for it provides a direct measure of one of the principal components responsible for a jump to occur - the force. Essentially the device is an electronic scale, which measures the magnitude of the vertical and two horizontal forces, the torque about the vertical axis and the location of the resultant force acting on the platform. ("The Use of Force Plates for Jumping Research.") The force plate was basically designed for standing/jumping tests, as it is the closest thing there is to flat ground. The only difference is that the ground (force-plate) has the ability to now record data in a replicated realistic situation. Jumping on to force plates help provide a force time that records the activity, and one can compare and contrast force records made by the same jumper in order to determine changes in the

users technique. This technology has opened numerous doors in the field of jumping research, and gives scientists the most accurate data based on landing and gait studies.

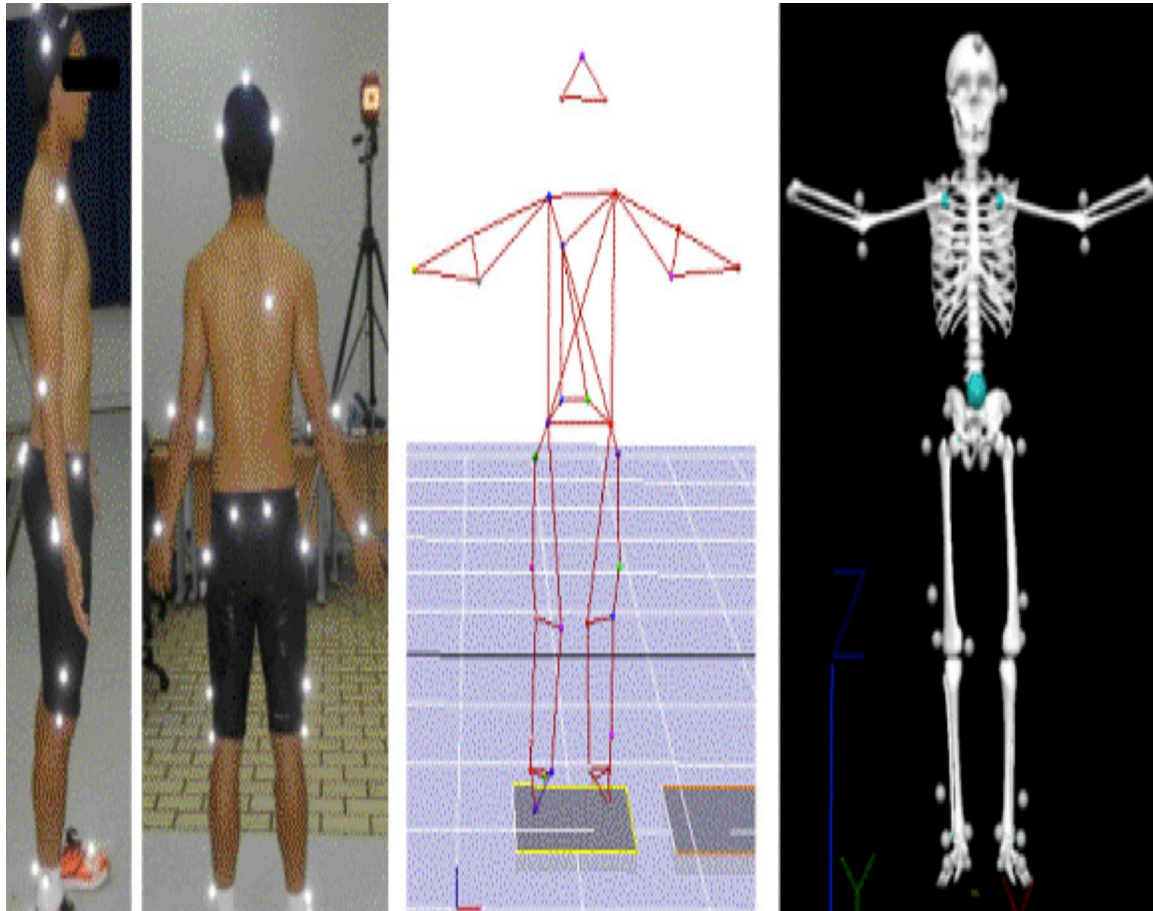


Figure 20: Jumping research patient

3.6 Paul D. Contnoir's Findings

The focus of Paul Contnoir's dissertation is on the use of influential computational algorithms, methodologies, and engineering interpretations to attenuate harmful road-induced vibration experienced within the patient-care and diagnosis compartment of an ambulance. It will be shown how standard patient care and diagnoses

are impacted by road vibration. The ultimate goal of this dissertation is to develop, model, and validate an active force plate design capable of working in tandem with a standard ambulance suspension system that is capable of attenuating the most harmful vibrations encountered by such a vehicle in normal service. The significance of this dissertation work lies in the lives which can be saved and the trauma avoided through the assessment and administration of mobile medical interventions with improved precision, accuracy and safety. Studies associated with ambulance modernization have indicated a need for a smoother ride in patient compartments in order to reduce the likelihood of ride-induced patient trauma, increase the occupational safety of emergency medical service (EMS) crews, and to increase the scope and raise the standard of care of mobile, in-route treatment and diagnosis. Over the years a variety of analytical and empirical methods have been developed to predict discomfort caused by vehicle vibration due road excitations. Automotive designers design vehicle suspensions with a proper combination of stiffness and damping to support vehicle loads, isolate road shock from the passenger compartment, maintain vehicle contact with the road surface, and allow proper vehicle cornering. A list of various studies and finding can be found in **Table 3**.

Table 3: Peer-reviewed studies dealing with risk of injury and death in ambulances and other emergency vehicles

Study Authors	Findings
Kahn, et. al., 2001	This study targeted ambulance crashes only from the NHTA Fatality Analysis Reporting System database and found that unrestrained patient compartment occupants were at the highest risk of injury in an accident. The authors also determined the typical high rate of speed of ambulance travel is often a contributing factor to accidents.
Maguire, et. al., 2002	The authors' analysis of various data sources suggests that the occupational fatality rates for EMS workers is greater than that of all workers and is on par with the fatality rates of other emergency public service workers.

Sterud, et. al., 2006	The results of this review of 49 independent studies of ambulance service occupational health issues corroborates other studies which indicate a higher standardized mortality rate than other professions, but further suggests additional risks of developing work-related health problems including: higher than normal rates of anxiety, general psychopathology, musculoskeletal problems and a higher standardized early retirement on medical grounds than the general working population.
Pirrallo & Swor, 1994	In this study, the authors failed to find any statistically significant differences in between the rate of fatal ambulance crashes during emergency or non-emergency use. The results of this study led the authors to conclude that the data was unable to provide much in the way of objective measures which would be useful in developing policies to decrease the number of fatal ambulance crashes.

Occupational safety of ambulances through the avoidances of danger and more specifically traffic accidents can be found in **Table 4**.

Table 4: Peer-reviewed studies dealing with suggested remediation to enhance ambulance safety

Study Authors	Findings
Levick & Grzbieta, 2008a	In this study, the authors propose that ambulance design and safety testing should be on par or exceed accepted automotive guidelines for dynamic crashworthiness test procedures.
Johnson, et. al., 2006	The authors' surveyed 302 EMS personnel regarding child and provider restraints for ambulance patient compartment occupants. Results of the survey suggest restraints are underutilized. Conclusions included that improved equipment may help alleviate some risk and allow for safer ambulance transport of pediatric patients.
Siedel & Greenlaw, 1986	This study corroborates the Johnson study and calls for a means of safely restraining infants and children in ambulances.
Elling, 1989	In this study, the author suggests the creation of better ambulance driver education programs, making ambulance drivers more aware of the hazards inherent in emergency vehicle travel, and adjusting agency standards to require ambulances to come to full stops at all stop signs and red lights, etc.
Levick & Swanson, 2005	This study investigated the feasibility of using an on-board computer monitoring system in ambulances to improve driver risk behaviors. Results included an increase of 15 miles between penalty counts, a drop in seatbelt violations and 20% saving in vehicle maintenance costs within a 6-month period. 36 vehicles with 250 drivers covered

	1.9 million miles over an 18-month test period.
Levick & Grzebieta, 2008b	The authors identify safety-testing requirements for ambulances, outline the basic principles of crashworthiness design and evaluate the design and construction of characteristic ambulances from a safety perspective. Detailed information on design and construction is included.

The tests that are involved in the analysis and protection of human passengers can be summarized by Pashold in **Table 5**.

Table 5: The natural frequencies of the human body

Study authors	Natural frequency (Hz)	Body, part or organ
Randall, Matthews & Stiles, 1997	12	Whole body, standing
Brauer, 1994	4 -6	Whole body, seated
Brauer, 1994	3- 4	Whole body, supine
Wasserman, 1996	4- 8	Whole trunk, vertical
Kroemer and Grandjean, 1997	4*	Lumbar vertebrae
Brauer, 1994	20-30	Head, relative to body
Kroemer and Grandjean, 1997	5-30*	
SafetyLine Institute	20- 30	
Mansfield, 2006	20	
Kroemer and Grandjean, 1997	20- 70*	Eyes
SafetyLine Institute, 2007	20- 90	
Kroemer and Grandjean, 1997	5*	Shoulder girdle
Kroemer and Grandjean, 1997	3- 6*	Stomach
SafetyLine Institute	4- 5	
Kroemer and Grandjean, 1997	4- 6*	Heart
Kroemer and Grandjean, 1997	10-18*	Bladder

Further studies showing the general responses to vibrations that affect the whole body can be found in **Table 6** and can provide significant information on the effects.

Table 6: Peer-reviewed studies dealing with general physiological responses to whole-body vibrations as reported by Mansfield

Systemic Category	Study Authors	Findings
	Griffin, 1990, p174	In the range of 2 – 20 Hz, moderate to high magnitudes of vertical vibration produce a cv

Cardiovascular (cv)	Griffin, 1990, p174	response similar to moderate exercise including elevated heart and respiration rates as well as an increase in cardiac output, mean arterial blood pressure, pulmonary ventilation and oxygen uptake. All these effects increase with increasing vibration magnitude around major body resonant frequencies.
	Uchikune, 2002, p 203-206	A 4% increase in heart rate was measured when seated subjects in a high speed vehicle were exposed to vertical vibrations in the range of 1.6-2.3 Hz and magnitudes of .26 - .43 m s ⁻² r.m.s., a 4% increase in heart rate. Subjects were seated and vibration measurements were made at their heads.
	Yue & Mester, 2007a, p. 107	The authors of this study, associated with vibration assisted conditioning, found that human exposure to vibrations in the 40-50 Hz range resulted in an increase in the maximum shear stress at the walls of major coronary arteries and veins at even at local amplitudes as small as 50 µm. This vessel dilation phenomenon has potential benefits for athletes due to the increased blood flow capacity, but may present health risks for individuals with existing cardiovascular conditions.
Cardiovascular (cv) (cont'd)	Yue & Mester, 2007b, p. 123	<ul style="list-style-type: none"> • The results of this study suggest that whole body vibrations which produce local vibrations in excess of 40 µm lead to the dilations of small blood vessels, particularly arterioles of up to 30%. This dilation led to a significant observed reduction of total peripheral resistance – an important ability of the human body to prevent the blood pressure from getting too high during high levels of exertion. • The distribution of local vibrations is dependent on the vibration amplitude and body transmissibility. • Transmissibility depends on vibration frequency and location as well body posture and muscle state. • Vibrations are transmitted through both muscle and skeleton separately and in concert. Transmissibility through muscle tissue varies with muscle activation.
	Green, et. al., 2006	In simulated rides over rough road surfaces, subjects displayed prolonged mild hypocapnia (lower than normal levels of CO ₂ in the blood stream brought on by tachypnea (elevated respiratory frequency) along with initial increases in heart rate and blood pressure. The authors feel this could be significant for individuals with impaired cardiovascular function who must travel in an ambulance over rough roads, or in evacuation from a combat or disaster zone.
	Clark, et. al., 1967	The authors found evidence of cardiovascular effects, including changes in mean arterial pressures and pulmonary edemas in response to short-term

		vibration in male adults subjected to whole-body, x-axis sinusoidal vibrations of 1g in frequencies ranging from 4 – 12 Hz. for 3 minutes.
Respiratory	Green, et. al. , 2008	This study included simulated rides over rough road surfaces identical to the authors' 2006 study. Subjects displayed prolonged mild hypocapnia (lower than normal levels of CO ₂ in the blood stream brought on by tachypnea (elevated respiratory frequency) which the authors feel could be significant for individuals with impaired respiratory control who must travel in an ambulance over rough roads, or in evacuation from a combat or disaster zone.
	Ernsting, 1961	The author reported hyperventilation and increased oxygen consumption on exposure to high frequency vibration.
	Dupuis, 1969	The author reported decreased respiration frequency, but increased respiration volume on exposure to vibrations in the 2-10 Hz range at a weighted magnitude of 1.25 m s ⁻² .
	Sharp, et. al., 1975	This study found that constant-displacement sinusoidal vibration in the 2-10 Hz range resulted in increased oxygen uptake due to hyperventilation and muscle tension. The effects were greatest at the highest frequencies.
Endocrine and metabolic	Litta-Modignani, et. al., 1964	The authors reported small, but significant changes to steroid levels in blood and urine samples of human subjects exposed to short term whole-body vibrations. All readings were within normal levels.
	Pushkina, 1961	This study reported hypoglycemia (low blood sugar), hypocholesterinaemia (low blood cholesterol) and low blood levels of ascorbic acids after exposure to vibration.
Motor processes	Roll & Roll, 1987	The authors found that vibration applied to the muscles of the eye influenced proper orientation of the eye relative to posture
Motor processes (cont'd)	Eklund, 1972	The author found a variety of adverse effects to balance due to exposure to whole-body vibration
Sensory processes	Moseley & Griffin, 1987	This study points to a possible link between vibration and biodynamic eye reflex movement. Evidence is also presented vibration effects on vestibular systems which can result in instability, disorientation of body, and disruptions of vision.
Central nervous system	Ullsperger & Seidel, 1980	The authors found that 4 Hz whole-body vibrations produced significant decreases in EEG amplitudes which may have an effect on perception thresholds.
Skeletal	Klingenstierna & Pope, 1987	This study found a temporary reduction in body height of around 10-20mm upon exposure to whole body vibration
Other	Roman, 1958	The author found that whole-body vibration tests at 25 Hz and +/- 1g to +/-10g amplitude ratings with exposures of 3 to 15 minutes produced severe chest pain and gastrointestinal bleeding at the highest

Roman, 1958	settings and exposure times.
Loeckle, 1950	The author reported traces of blood in the urine of a man with a kidney stone at 30 Hz and +/- 9g accelerations
Gratsianskaya, 1974	The results of this study indicates menstrual disorders, internal inflammation, and abnormal childbirth in women exposed to 40-55 Hz vibration.

Effects on the body that have physiological effects as well as minor complications with everyday task were tested and can be found on **Table 7**, while **Table 8** shows the road profile descriptions as well as more physiological effects.

Table 7: Summary of resonant frequencies of body systems and their resulting physiological effects.

Resonant Frequency (Hz)	Body part, organ, or system	Physiological effect
.3	Inner ear	Motion sickness
1 - 4	Respiratory	Hyperventilation
2 - 8	Motor skills	Difficulty performing simple target tracking tasks, handwriting etc.
4 - 6	Brain (cognition)	Fatigue, loss of concentration
4 - 8	Inner ear, heart	Balance and sway problems
5 - 20	Speech	Difficulty speaking clearly
20 - 30	Spine	Back disorders &, pain
10 - 20+	Vision	Diff. tracking objects, reading, blur

Table 8: Typical frequency, vibration levels, measurement configuration, road profile descriptions and physiological effects of ambulance vibration studies

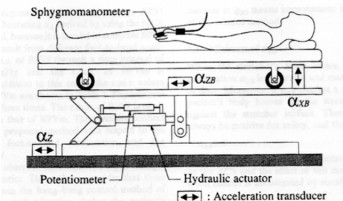
Study Authors	Vibe. Freq. (Hz)	Peak accel. (m s^{-2})	R.M.S. accel. (m s^{-2})	Road profile description	Measurement configuration	Physiological effects
Sherwood, et. al., 1994	--	15	--	City & highway	Triaxial vector sum measurement on mannequin forehead, vehicle floor and base of isolette	Clinical significance requires further study but vibrations exceed ISO guidelines.
Bellieni, et. al., 2004	5	11.8	1.3	City & highway	Vertical axis in isolette, on passenger seats, & on driver's seat	Clinical significance requires further study but vibrations exceed ISO guidelines.

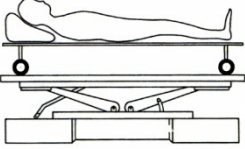
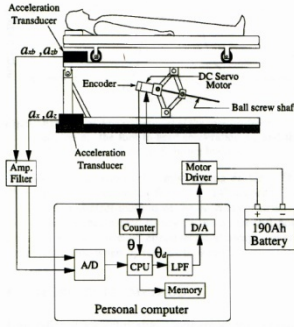
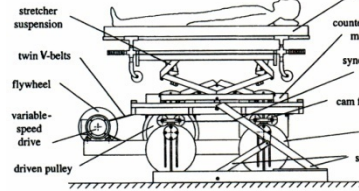
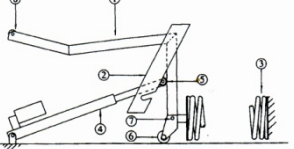
Shenai, et. al., 1981	3 – 18	5.0 – 13.0	2.2 – 6.0	Highway @ 48 mph	Vertical axis on supine infant head, abdomen, thigh	Clinical significance requires further study but vibrations exceed ISO guidelines.
Silbergleit, et. al., 1991	1 – 15	3.1 – 8.1	.7 – 1.9	Bumpy road, city road and highway	Triaxial vector sum measurement on standard backboard at head position	Clinical significance requires further study but vibrations exceed ISO guidelines.
Mcnab, et. al., 1995	< 50	0 – 1.7	.0 - .7	Bumpy road, city road and highway	Triaxial vector sum measurement from acoustical measurements	Clinical significance requires further study but vibrations exceed ISO guidelines.
Pichard, et. al., 1970	1	.16 - .85	--	City & highway	Z-axis, head-to-toe of recumbent patient	30% of patients suffered a variety of untoward events including cardiac arrest, arrhythmias, nausea, and respiratory distress
Weber, et. al., 2009	--	--	--	City & highway, 15 min drive, Vienna, Austria	--	A significant rise in plasma catecholamine levels (indication of stress) was noted and attributed at least in part to the ambulance transport
Schneider, et. al., 1988	--	--	--	Unrecorded surface < 50 mi radius	--	<ul style="list-style-type: none"> • All patients studied were diagnosed with either myocardial infarction or unstable angina prior to transport. • A total of 7% of patients experienced a variety of untoward events including: arrhythmias, chest pain, hypotension, bradycardia, seizures, cardiac arrest, nausea, vomiting, equipment failure (ambulance) or IV

						line loss during transport
Witzel, 1999	--	--	--	Paved road – 72 km hr ⁻¹ for 13 km w/ siren	--	<ul style="list-style-type: none"> Heart rate increased 30% over slow ride within first 8 min. and remained high throughout trip Mean arterial pressures of 122 – 130 mm Hg. Cortisol blood level increased 60% at peak
				Paved road – 40 km hr ⁻¹ for 13 km w/o siren	--	<ul style="list-style-type: none"> Heart rate 30% lower than fast ride peaked within 2 minutes and returned to normal prior to end of trip Mean arterial pressure 108 mm Hg. Cortisol blood level increased 30% at peak

Stretcher systems for ambulances were also tested as well as the stretcher suspension and those findings can be found on **Table 9**.

Table 9: selected vibration absorbing stretchers and stretcher suspension systems for ambulances.

Study authors		Stretcher/suspension design
Sagawa, et. al., 1997 (manually control)	This design succeeded in using pitch angle of the stretcher to help stabilize the patient's blood pressure. Success at controlling vibration was inconclusive.	

Snook & Pacifico, 1976	Double electrically controlled electric motors in concert with compression springs produced reductions of up to 66% in peak acceleration values over a normal stretcher in the 3 to 10 Hz range	
Sagawa & Inooka, 2002 (actively controlled)	The authors claim this servo-controlled electric design maintains the patient at $.45 \text{ m s}^{-2} \pm 1.32 \text{ m s}^{-2}$ within a frequency range of 0 – 70 Hz.	
Henderson & Raine, 1998	In the 0 – 12 Hz range, this servo-controlled hydraulic design reduced r.m.s. accelerations from 64% to 85% depending on road surface.	
Leyshon & Stammers, 1986	With a mattress in place, this design attenuates ambulance floor vibrations by 7 db @ 1.5 Hz and 9 db @ 4 Hz.	 Fig. 3 Suspension system (one end) 1 Load arm 5 Pivot 2 Pivot guide 6 Reaction roller 3 Spring 7 Spring pivot 4 Actuator 8 Load arm roller

A key element in a gait laboratory is a force-plate, which may be used to measure the forces and moments applied by the foot onto the walking surface during a gait cycle. While many laboratories have relied solely upon motion data as obtained from using various camera techniques for analysis of gait, it is only with the inclusion of a force plate that the dynamic aspects of gait are appropriately considered. ("Rehabilitation Research & Development Service") Gait studies are one of the most popular uses of force-plates in the medical industry due to the pressure points that show up on the

program used with the force sensor.

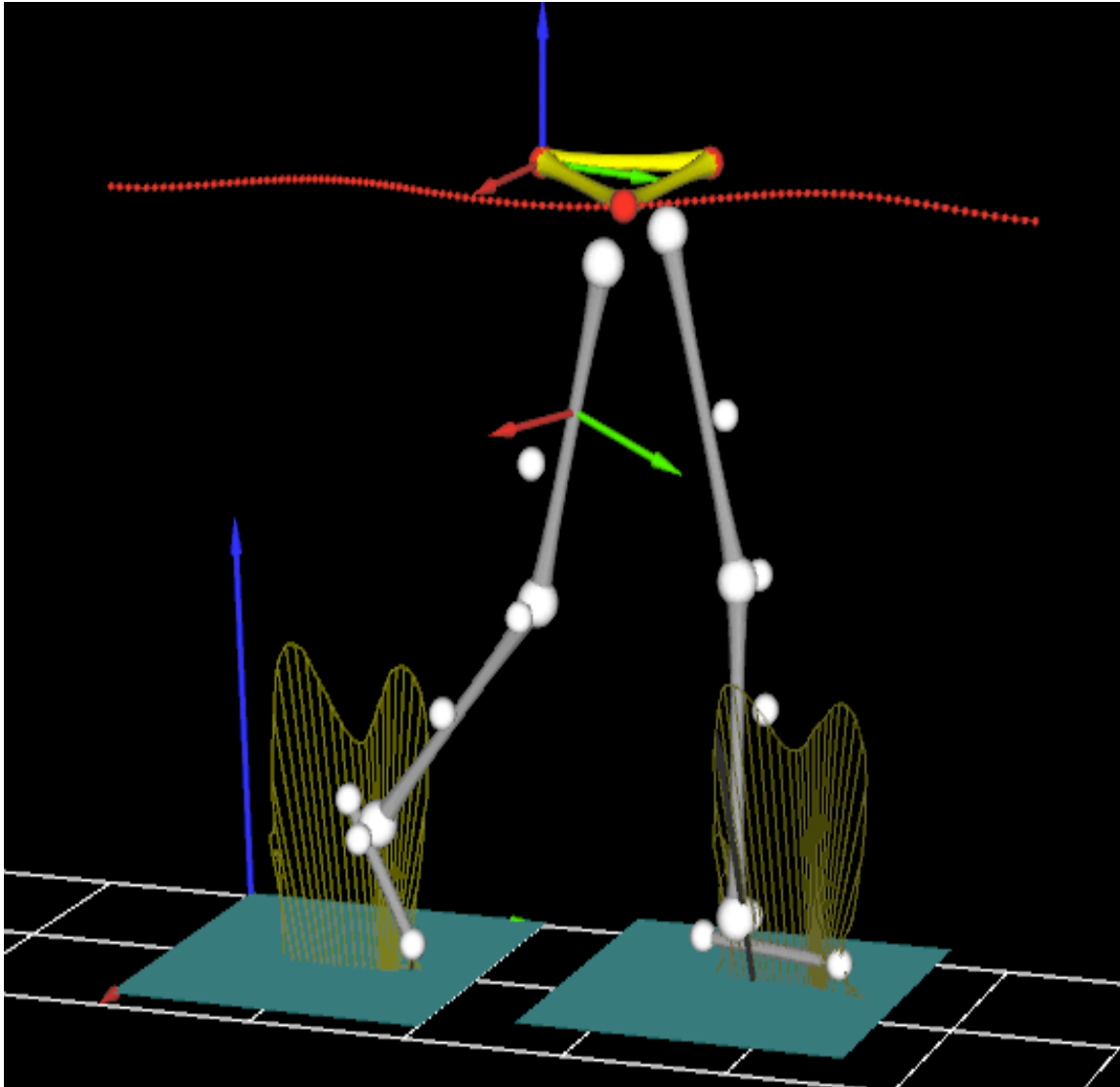


Figure 21: Gait Studies Test

During the stance phase of each gait cycle, the foot onto the walking surface develops a varied mixture of rapidly changing vertical weight, horizontal shear, and rotational twisting moments. If a complete footstep "force signature" is to be obtained, then each of the force and moment components must be sampled regularly at a sufficiently high rate ("Rehabilitation Research & Development Service"). This data helps patrons and companies release products that aid in gait studies.

CHAPTER 4: FORCEPLATE DATA ANYALYSIS

4. Introduction

In our first step to initializing the program, we made sure all necessary accessories to both the force plate and the CPU were connected correctly. We then turned on the computer and double-clicked on the AMTI NetForce link on the desktop.

4.1 Forceplate Data Analysis

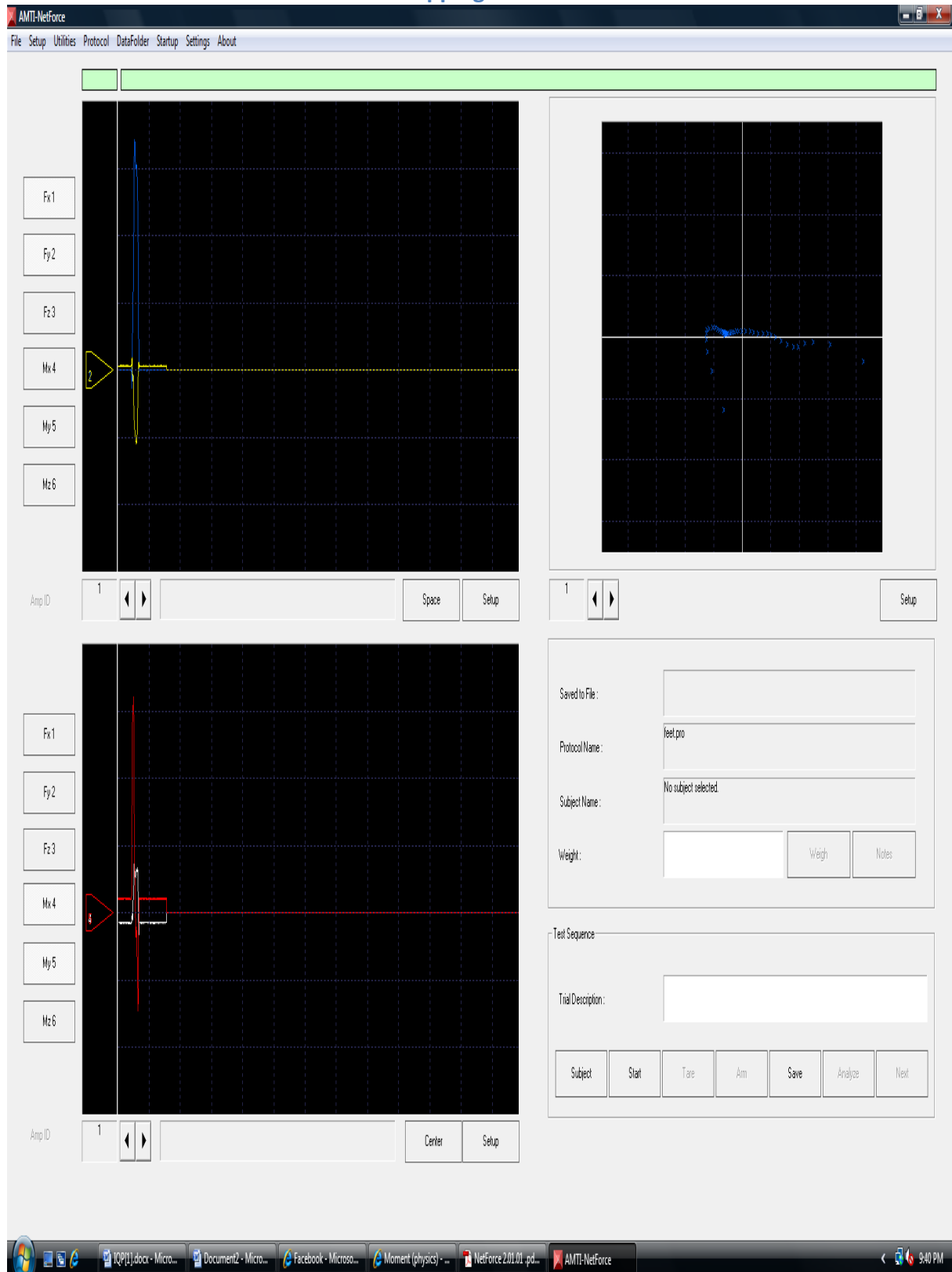
The following error message than appeared on the screen: Title: “AMTI NetForce” Message: “unnamed file was not found.” We then proceeded to click on the startup option in tool bar. Selected System Check and received a message stating press start first. Pressed Start button, no result. Then selected System Calibration received same error message. Proceeded to press Start button again, once again no result. Unable to start program. Attempted to create new file for use, followed required steps, received error message: unable to initialize configuration file. Pressed OK, new error message came up stating, “Creation of AMTIBioNet.dta in C:\ProgramFiles\AmTI failed! Call AMTI tech support.” Program then shut down again. Rechecked all inputs and outputs making sure system was connected correctly. All connections correct. Restarted program. Went through setup steps to make sure program was installed and working correctly. Clicked on the “Setup” tool in the tool bar, and selected the option Setup Helper. Program asked “Is your application primarily Biomechanics?” Selected “Yes.” Next selected AccuSway Serial (using RS-232). Then asked to select configuration file, chose Balance 50 (Recommended for AccuSway applications). Received error message “Unable to save configuration file!” Hit Enter, selected United States and English on following message box. Received same message, as before stating, “unnamed file was

not found.” Program setup stopped, unable to continue. Proceeded to attempt to create new file, every time received error message titled Microsoft Windows stating “AMTINetForce Application has stopped working- a problem caused the program to stop working correctly. Windows will close program and notify you if a solution is available.” Program stopped, was forced to reopen program, reattempted setup multiple times receiving same error message at same point every time. Assumed problem with Windows running the AMTI-NetForce software. Images of all error messages are included in the PowerPoint.

After numerous tries to operate the system we unplugged everything, plugged it back in, and proceeded to run tests. The system was fixed after we did that, and no error messages occurred. This was noted that the correct way to test the connections was to disassemble and re-assemble the equipment.

Several tests were conducted to show different forces and different moments of everyday things such as walking, standing, leaning, etc. as shown in the following figures. In all figures the blue line represents F_x , the force in the x-direction, yellow line represents F_y , bright green line represents F_z , white line represents M_x , the moment in the x-direction, the red line represents M_y , and the burnt orange line represents M_z . Units/division are in Newton’s (N) for force and Newton’s-meter (N-m) for moments of inertia. The units/division for each particular graph is given in the description of each graph.

4.1.1 Force and Moment of Inertia of Stepping With One Foot



Graph 1.1: Stepping One-Footed Onto Force Plate at Center



Graph 1.2: Stepping One-Footed Onto Force Plate at Center

Graphs 1.1 and 1.2 show the forces and moments of a 210 lb, or 95.25 kg student stepping with his left foot onto the force plate, stepping parallel to the x-axis in the center of the plate. The first spike seen is the initial time that the foot touched the force plate, with the second spike downward being the time the foot was retracted from the plate. Graph 1.1 shows the forces and moments in the x and y directions, while Graph 1.2 shows the forces and moments in the z direction. The units/division on for both graphs represented are $F_x=50$ N, $F_y=50$ N, $F_z=500$ N, and M_x , M_y , and M_z equaling 10 N-m in both graphs.

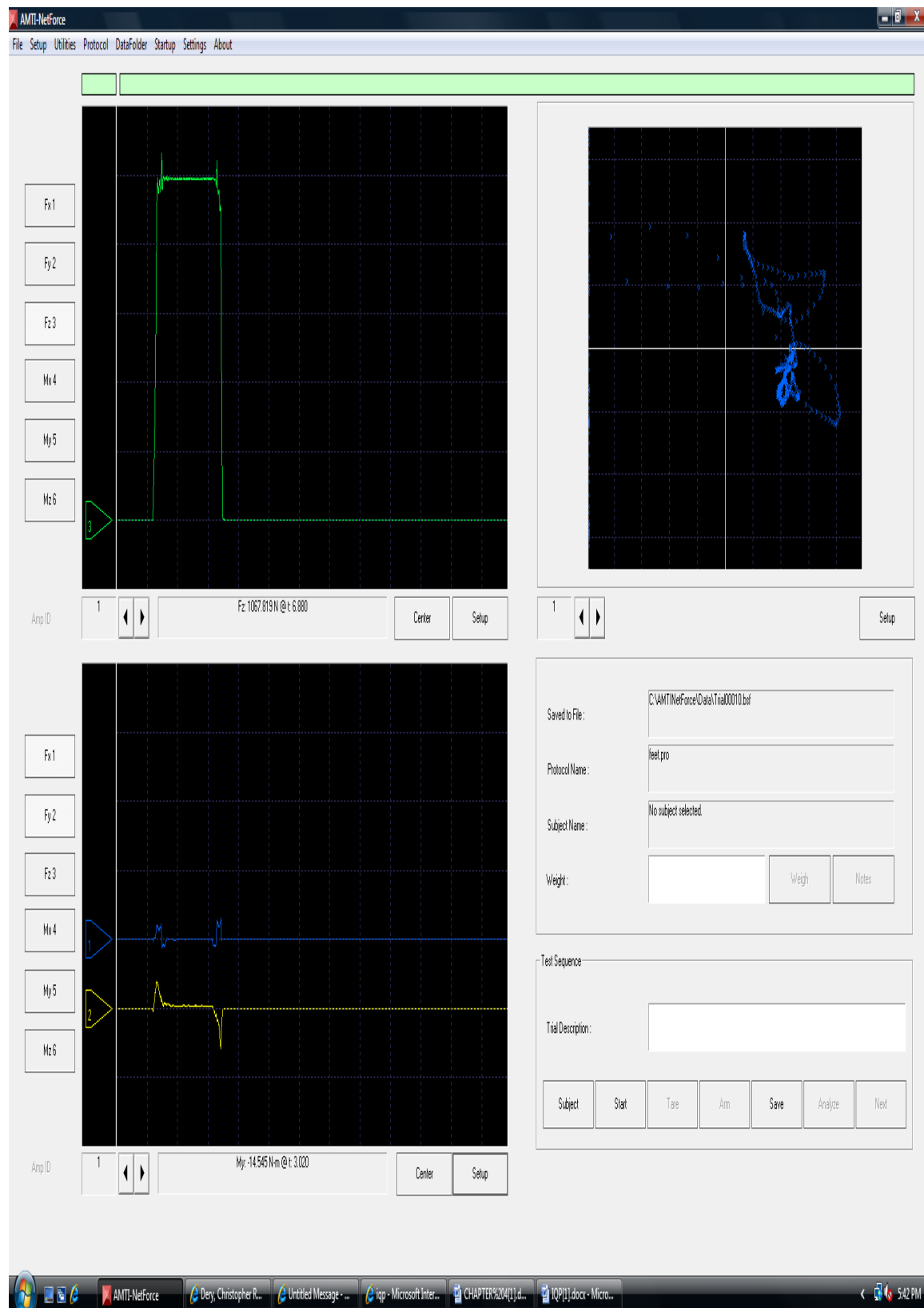
As shown, the force of the foot touching the plate is substantially smaller in the x and y directions than the z-direction, with the peak $F_z=916.799$ N. This makes sense as the most force coming from a downward step is going to be perpendicular to the ground. The F_y force in the negative direction are explained by the different parts of the foot coming into contact with the force plate, with the heel of the foot initially landing and putting pressure in the $-y$ -axis. The heel touching initially in the $+x$ side of the axis on the force plate as the step was taking coming from the positive direction on the x-axis explains the force in the positive x-direction.

The largest moment measurement was in the y-direction, with a measurement of 32.044 N-m. As the heel touches on the positive side of the x-axis, it turns to touch in the negative x-axis. Thus, the rotational force travels around the y-axis. This happens the instant the heel touches the force plate and the toes begin to approach the plate. As the foot is retracted back, the ball of the foot and toes push off resulting in a reverse in the moment as shown in the graph. The value of the moment as the foot is retracted in the y-direction was -14.545 N-m. There are also slight moment measurements in the x and z

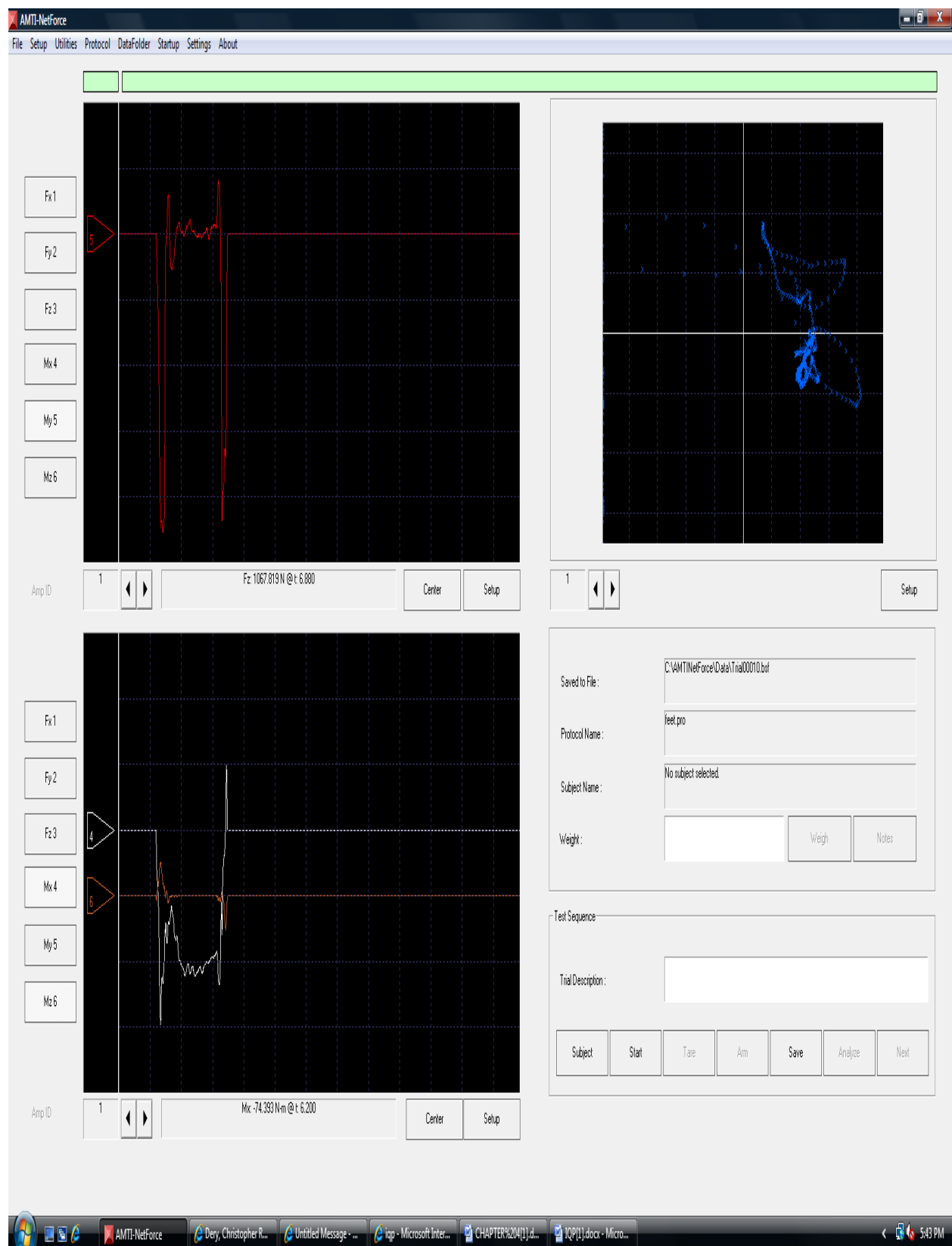
directions, which are assumed to be explained by foot shape and pressure points, as well as accounting for the heel touching first and then the ball of the foot. The negative M_z comes at the time of the removal at the foot, which can be explained by the pressure points of the foot being on the outside of the left foot do to the arch in the subject's foot.

4.2 Walking Onto the Force Plate with Two Feet

The following shows the results from walking on the forceplate with two feet and subsequently stepping off. The jumps on either side of the graph indicate whether I had stepped on of stepped off of the forceplate. Moments were recorded at all intervals of this test and analyzed,



Graph 2.1: Walking on the Force Plate, Stopping with Both Feet, And then Stepping Off



Graph 2.2: Walking on the Force Plate, Stopping with Both Feet, And then Stepping Off

This section of the project shows the forces and moments of a person stepping onto the force plate first with their left foot, then with their right such that both feet remain on the plate, facing in the positive y-direction. The person stood there for a few seconds, and then stepped off first with their right foot then with their left. The units/dimension for **Graph 2.1 and 2.2** are $F_x=200$ N, $F_y=200$ N, and $F_z=200$ N per dimension, and the moment values per dimension are $M_x=25$ N-m, $M_y=25$ N-m, and $M_z=25$ N-m. The first graph shows the force values, and the second graph shows the moment values from this section of the experiment.

The initial force of the foot hitting the force plate, as seen in **Graph 2.1**, scattered between 990-995 Newton's of force. When the second foot touches the plate, the plate recorded its highest force value at a peak of 1038.64 N. The force immediately went back down as soon as the foot was planted and steady, and remained and fluctuated between values of 990-995 Newton's as the subject stood flat-footed for several seconds. The average value F_z force value over the time the subject stood still on the force plate was 992.767 Newton's.

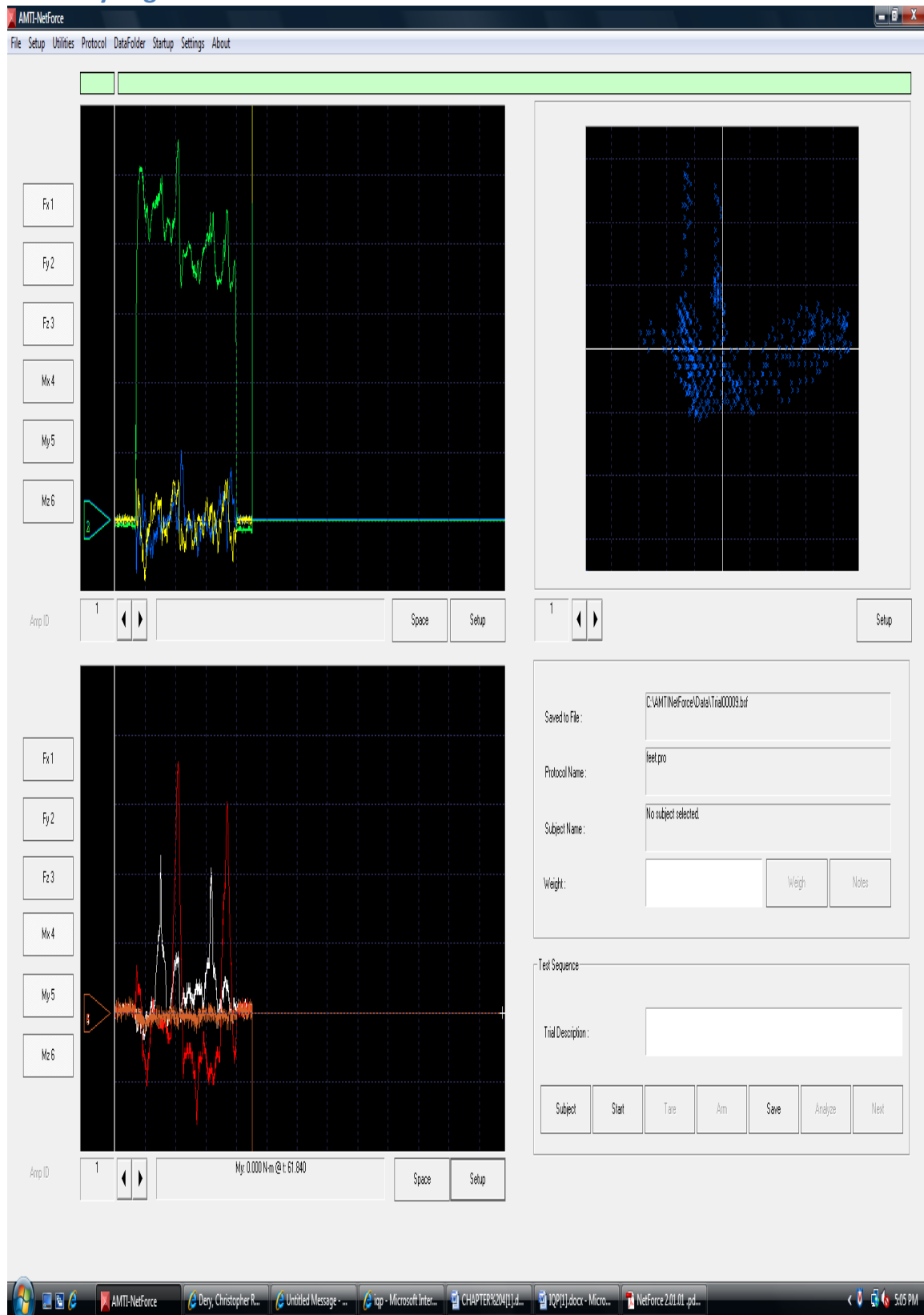
As the feet were retracted, there was once again a spike in the force graph this time caused by the person pushing off the force plate to move the foot back onto the ground. There is once again one solid peak in the graph as soon as the first foot pushed off the force jolted upward and immediately back down as soon as it was removed from the plate. This spike was not as high as the first, recorded at about 1021 Newton's.

There were slight but insignificant F_x and F_y values as well, which can be explained by the placement of steps, the shape of the foot, and the angles at which the feet hit the plate. The positive and negative F_y values occur because when the first foot touches the force is headed in the positive y direction. The force then stabilizes as in the

other graphs and goes in the negative direction when the subject steps off of the plate because the force is in the negative y-direction. The moments in this section are largely affected by foot placement, so only the values of the moment of the subject stepping off will be analyzed.

The moment around the x-axis (M_x) as the feet are removed from the surface of the plate was 25.012 N-m. As the foot goes to leave, the foot rotates over the x-axis in the positive direction, with the balls of the feet pushing off as the heel comes upward and forward. The M_y value fluctuates from positive to negative because the right foot leaving causes all the force to move to the left foot, resulting in all the force being moved to the negative side of the y-axis. Thus, there is a moment M_y caused by the weight transfer from both feet to just the left foot. The M_y value when the right foot is pushing off of the plate was 19.164 Newton's-meter, which then plummets down to -113.995 Newton's-meter as the left foot is pushing off.

4.3 Analyzing Elbow Rotation



Graph 3.1: Elbow Rotation

In this section, the forces and moments of elbow rotations will be analyzed. The units/division in the graphs shown are $F_x=10$ N, $F_y=10$ N, and $F_z=15$ N, $M_x= 1$ N-m, $M_y=1$ N-m, and $M_z=1$ N-m.

The subject leaned onto the force plate, which was placed, on the corner of a lab table, with their elbow placed directly in the center of the x-y plane. The elbow was kept at a right angle, and rotated without removing the elbow from the origin with the wrist coming in a downward motion in the negative y-direction towards the table. The arm was then brought back perpendicular to the scale, and the forearm was extended straightforward without removing the elbow from the origin to about 1 inch from the wrist touching the scale. The arm then once again came back to its original position, and then brought downward to the right in the positive y-direction in the same matter as the original movement in the negative direction. Each of these steps was then repeated.

Once again, the z-value was by far the most substantial in force. The peak F_z value came at $t=9.6$ seconds, the time at which the elbow fold to the right occurred. The force was measured at 79.885 Newton's. As this is an extremely irregular motion, it makes sense that this motion required the highest amount of force. The elbow rotates easily inward and forward, but not as easily outward as shown by this measurement. The force of the elbow originally touching the pad measures 76.412 N. This increase is not that far from the original force recording mathematically at just 3.47 N, but is extremely noticeable on the graph as the force dips in between every rotation, as the elbow is steady.

The key analyses in this section are the moments of each motion in the x and y directions. Each spike in the bottom graph shows a different motion, with the first small

upward spike being the elbow touching the pad. The second spike downward is the first motion left. The next upward white spike is elbow opening forward, and the following upward red spike is the first movement to the right. Each following spike is the same in the same order.

The first rotation to the left had a M_y measurement of -0.95 N-m, as the arm rotated around the y-axis in the negative x-direction as the wrist came down towards the table. The second time the rotation left occurred, the measurement was higher, measuring -1.464 N-m. After the motion to the left occurred, the forearm was extended forward with the elbow opening up. The two forward motions had an average M_x value of 2.21 N-m. As the elbow opens up forward the rotation moves in the positive x direction around the y-axis, resulting in a positive x moment value. The next spike is the rotation to the right. The first right motion made in the positive x-direction lead to a M_y recording of 3.482 N-m. The second resulted in a M_y value of 3.059 N-m. As this was the most irregular motion as stated before, it makes sense that this motion caused the highest spike in N-m value. As the elbow was placed parallel to the y-axis, the movement in the positive x-direction causes a positive M_x recording.

CHAPTER 5: CONCLUSION

5. Calculations

All calculations made make sense theoretically and mathematically. All moments moved in the expected directions. The moments caused by stepping onto the force plate show the moments occurring in the ankle and the rotation of the ankle. The measurements in section 4.3 show that of the elbow. This experiment helped further our knowledge of moments and how they occur, and also determine the physics of different everyday motions. The proper form to stand on a force plate can be found in **Figure 14**. It is crucial that you are evenly lined up on the x and y-axis in order to record accurate results in real time.



Figure 22 - Standing on Force-Plate

Force-plates come in a variety of shapes and sizes that aid in a number of different tasks for the greater good of the organism. The specific force-plate that we used was

manufactured by AMTI and can be found in **Figure 15**. The force-plate was 19.75x19.75x1.77 inches, the complete specifications however can ultimately be found in **Figure 16**. **Figures 17-25** shows the proper way to connect the force-plate electronically and to the computer, it also shows every component that is involved with the actually force-plate. The pictures also offer different views of the force-plate and how each one interacts with the other seamlessly.



Figure 23 - Actual AMTI force plate being used

Units: English Capacity: 250

Dimensions (WxLxH)	19.75 x 19.75 x 1.77 in	Mounting hardware	Not Required
Weight	25 lb.	Sensing elements	Hall Effect
Channels	Fx, Fy, Fz, Mx, My, Mz	Amplifier	Built-in
Top plate material	Composite	Analog outputs	Optional
Temperature range	0 to 125°F	Digital outputs	6 Channels

Channel	Fx	Fy	Fz	Units	Mx	My	Mz	Units
Capacity	40	40	250	lb	-	-	300	in-lb
Sensitivity	-	-	-	μv/v-lb	-	-	-	μv/v-in-lb
Natural frequency	100	100	120	Hz	-	-	-	Hz

Figure 24 - Force-Plate Specifications

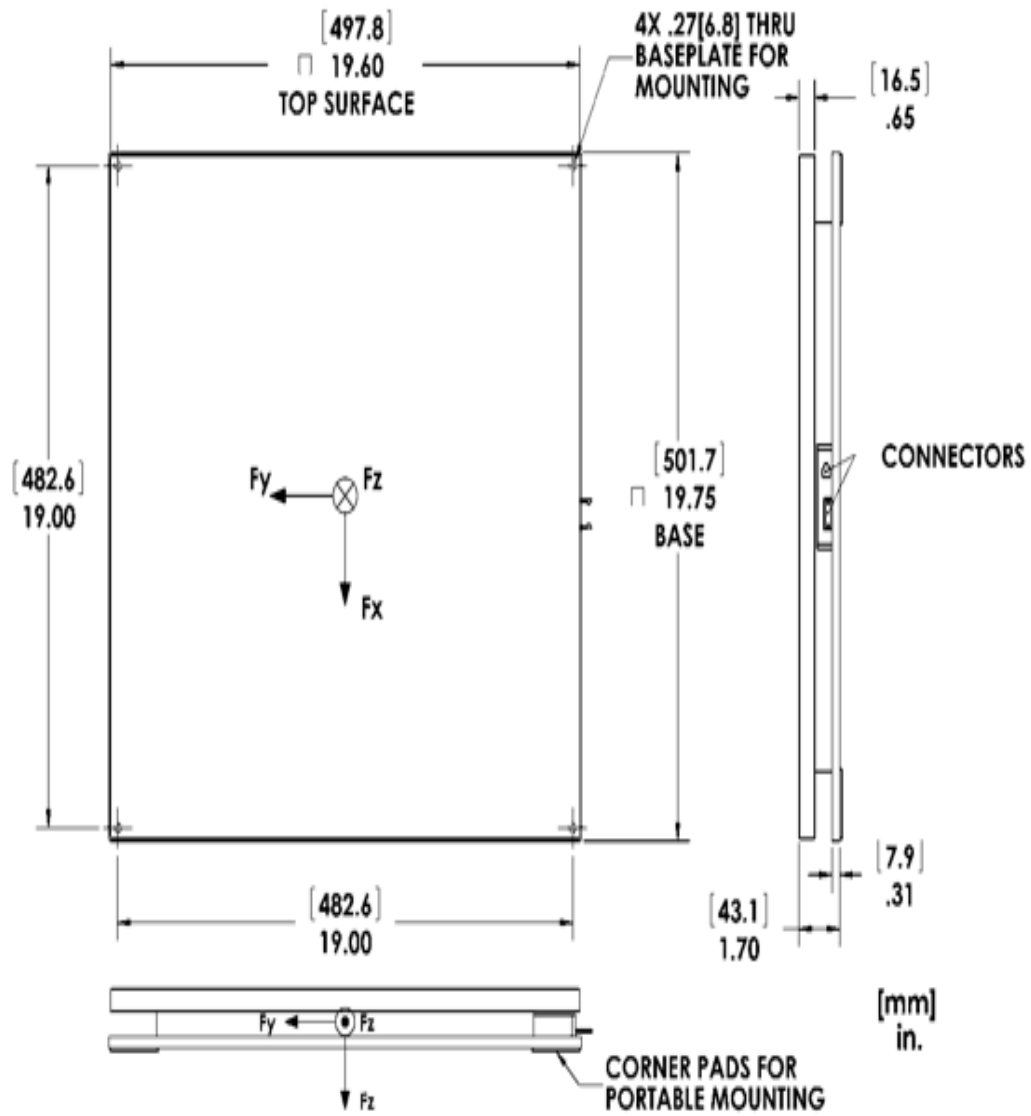


Figure 25 - AccuSway Schematic



Figure 26 - Side View of Connection Box



Figure 27 - Close-Up of Connection Box



Figure 28- Side View with Power Converter

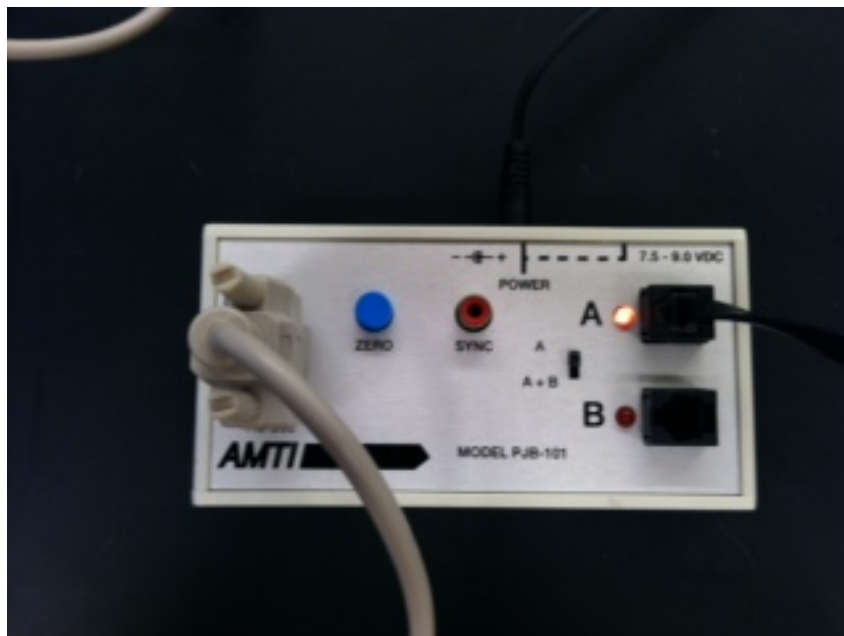


Figure 29 - Power Converter Box



Figure 30 - Top of Connection Box

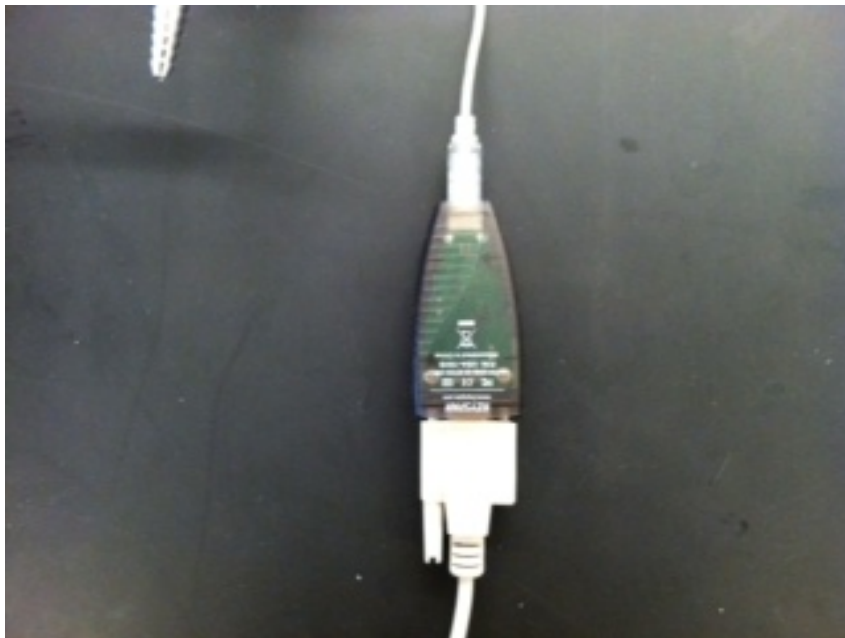


Figure 31 - USB Converter



Figure 32 - USB to CPU

In order to improve the total quality of care, one must evaluate the impact of road

vibration on the quality of ambulance care.

5.1 Vibrations

The road vibration has a great deal to do with this, as well as the overall performance of the AMTI force plate. Road vibrations can be caused from anything as vague as a bump in the road, to the smallest amount of vibrations caused from a running engine. Ambulances are rugged vehicles that get put through a lot of strain and pressure, as they are generally speeding to get to where they need. After the visit to the Boston EMS garage one can see that they have to be constantly checked in order to make sure everything is working properly.



Figure 33: Picture taken from Boston EMS trip

If the ambulance is not performing to its full potential then it is impossible for it to deliver proper care to patients. The Boston EMS garage had numerous lifts to work on ambulances as well as all the proper tools one would need. It was interesting to talk to

some of the workers there as they all had different stories as to the most extreme thing they have ever done. One mentioned that a wheel had blown and all the ambulances were out, he had to immediately change the wheel properly and get the ambulance back on the road safely before another call was dispatched to it. Of course cities are more apt to damages as they are fast paced and there are more potential people that could be in need of care. The following will go into all the specifics that allow the previous statements to perform properly. There is way more than meets the eye when dealing with EMS and ambulatory care, it is a fast passed world and their needs to be proper people in place to make things run smoothly.

There are many elements used in emergency medical services than meets the common eye. For starters when someone has an immediate issue that needs to be tended to than the first responders are usually EMS. The position that they are in is an extreme one that many people could find hard to fathom.



Figure 34: EMS badge and slogan

Split second life or death situations are always something to think about when talking about EMS. The moral and ethical choices that they must make become a viable part of the job. The network of technology that allows these officers to be dispatched properly is half the battle. Response time depends on how close the ambulance is to a particular crime scene. Based on how important the call is and how close they are, EMS officials are forced to make tough split second decisions daily. Traffic can be extremely hectic at times and response times can be highly altered. In a recent NAS report, it revealed that the average American had a greater chance of survival in the combat zones of Korea or Vietnam, than on one of our nation's highways, this helped to catalyze the creation of the EMS system we know today (South Carolina). In 1966, congress ultimately passed legislation enabling the creation of the National Highway Traffic Safety Administration (NHTSA). This helped to set the stage for the first federal standards in EMS, because of this our EMS systems 40+ years later helped make the United States the most advanced EMS system in the world. There still remains an underlying issue however, and that is funding. The EMS system still has to deal with the challenge of declining support for state and federal EMS programs.

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